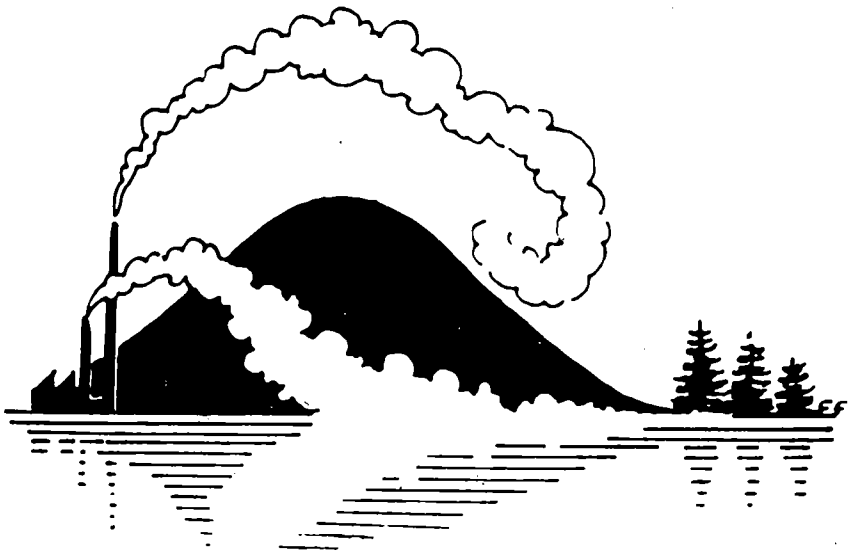
PROCEEDINGS OF THE AIR POLLUTION METEOROLOGY AND ENVIRONMENTAL ASSESSMENT WORKSHOP



ATMOSPHERIC ENVIRONMENT SERVICE
DOWNSVIEW, ONTARIO

Environment Canada / Environnement Canada
Atmospheric Environment / Environnement atmosphérique

MAY 7-10, 1979

CORRECTIONS TO:

"PROCEEDINGS OF THE AIR POLLUTION
METEOROLOGY AND ENVIRONMENTAL
ASSESSMENT WORKSHOP"

held at the

Atmospheric Environment Service
Downsview, Ontario

May 7 - 10, 1979

ERRATA

Pg. 128:

The differential of the plume equation Eq. (5) for a ground level estimate (z = 0) is found to be

$$\frac{d\chi}{\chi} = \frac{dQ}{Q} - \left(\frac{y}{\sigma_y}\right)^2 \frac{dy}{y} - \left(\frac{H}{\sigma_z}\right)^2 \frac{dH}{H} + \left(\frac{y^2}{\sigma_y{}^2} - 1\right)\frac{d\sigma_y}{\sigma_y} + \left(\frac{H^2}{\sigma_z{}^2} - 1\right)\frac{d\sigma_z}{\sigma_z} - \frac{dU}{U} \qquad (33)$$

The mean square of this ratio is, from Eq. (31), the sum of the mean squares of each of the error terms on the right side of Eq. (33).

$$e^2 = \overline{\left(\frac{d\chi}{\chi}\right)^2} = \overset{(.05)^2}{\left(\frac{dQ}{Q}\right)^2} + \left(\frac{y}{\sigma_y}\right)^4 \overset{(.1)^2}{\left(\frac{dy}{y}\right)^2} + \left(\frac{H}{\sigma_z}\right)^4 \overset{(.2)^2}{\left(\frac{dH}{H}\right)^2} + \left(\frac{y^2}{\sigma_y{}^2} - 1\right)^2 \overset{(.2)^2}{\left(\frac{d\sigma_y}{\sigma_y}\right)^2} + \left(\frac{H^2}{\sigma_z{}^2} - 1\right)^2 \overset{(.2)^2}{\left(\frac{d\sigma_z}{\sigma_z}\right)^2} + \overset{(.2)^2}{\left(\frac{dU}{U}\right)^2} \qquad (34)$$

Pg. 129:

$$e = (.0925)^{1/2} = .30$$

Pg. 388:

The following five figures should be included with the paper 'Alaska Highway Gas Pipeline Study'.

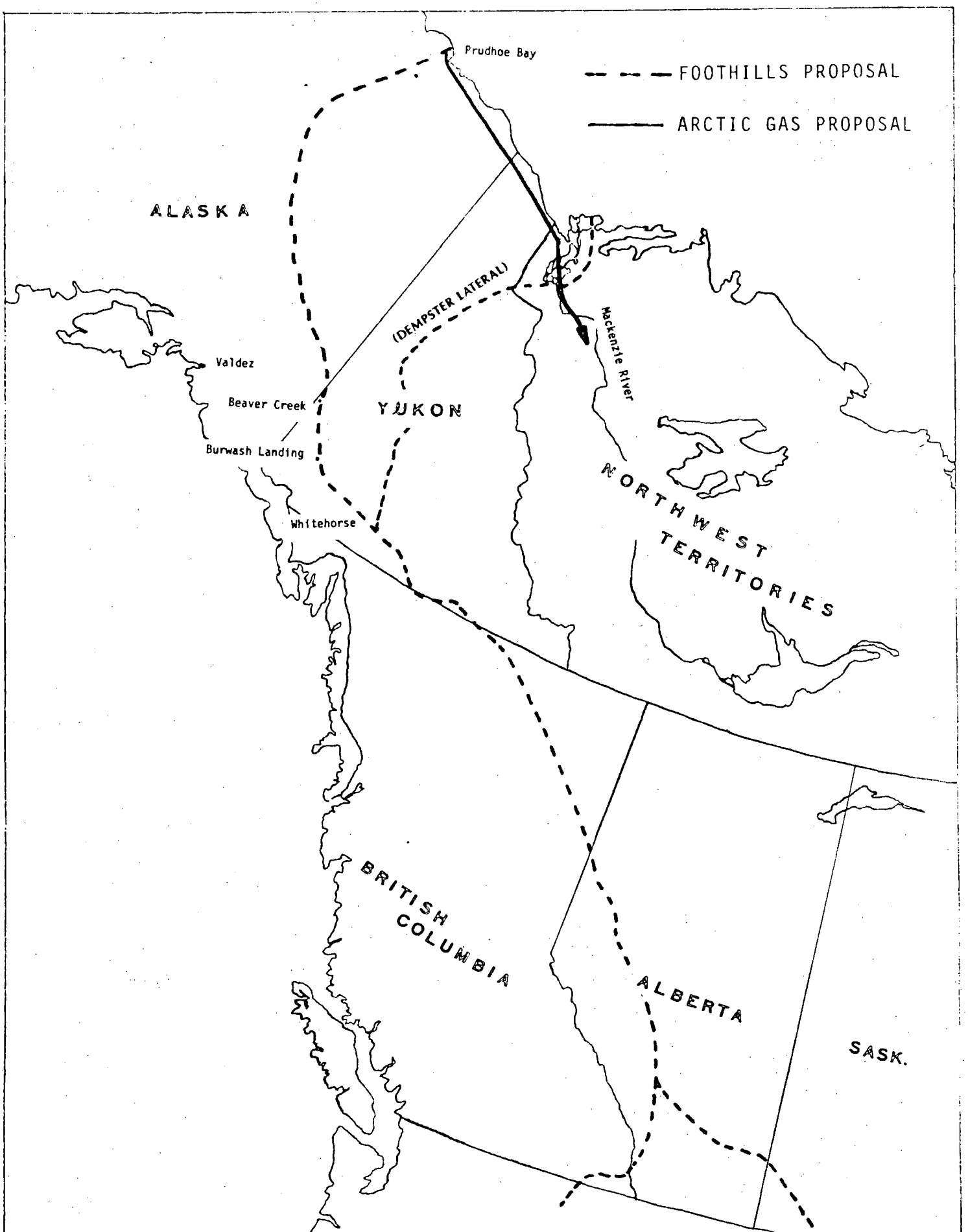


Figure 1. Proposed Pipeline Routes from Prudhoe Bay.

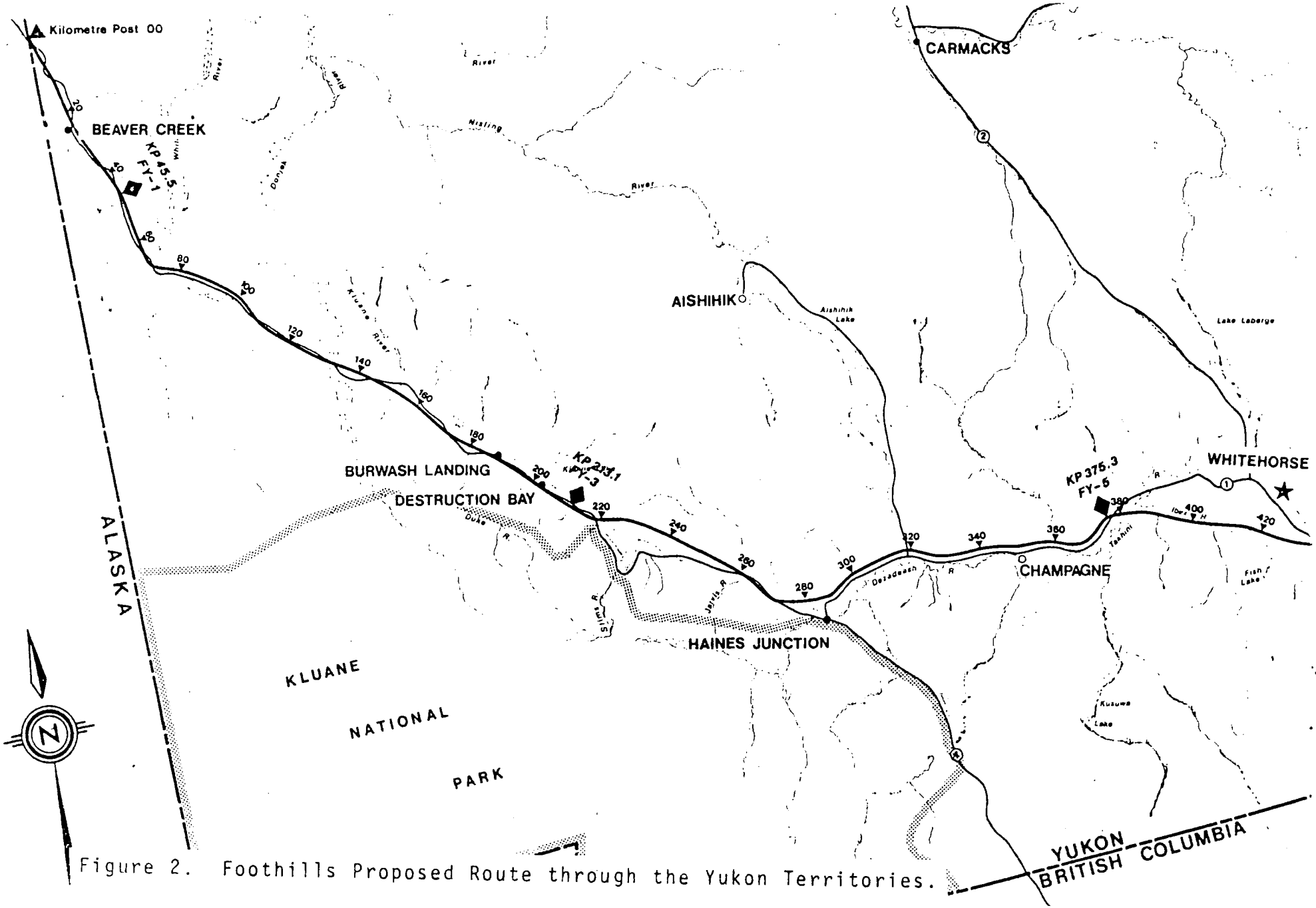


Figure 2. Foothills Proposed Route through the Yukon Territories.

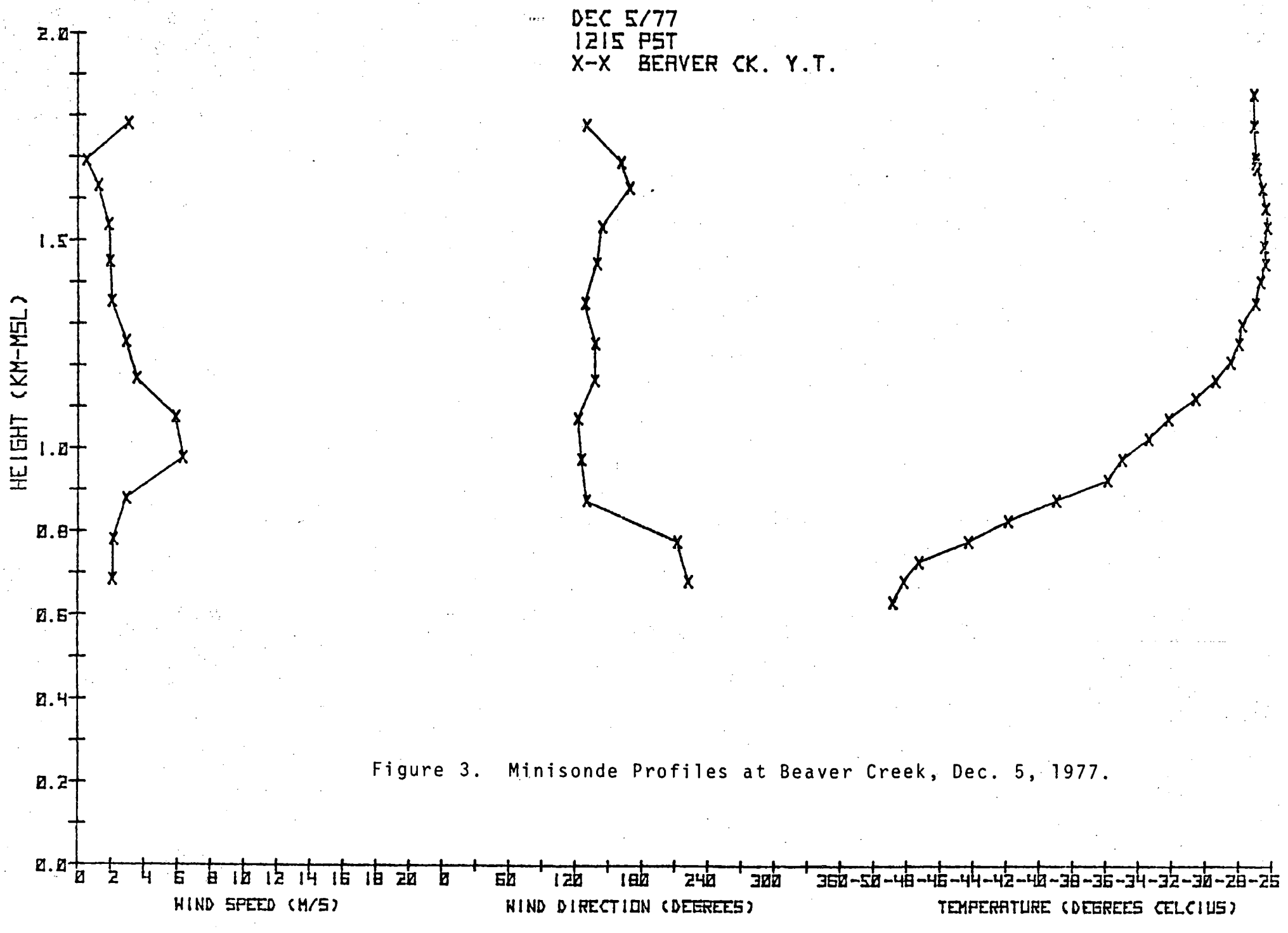


Figure 3. Minisonde Profiles at Beaver Creek, Dec. 5, 1977.

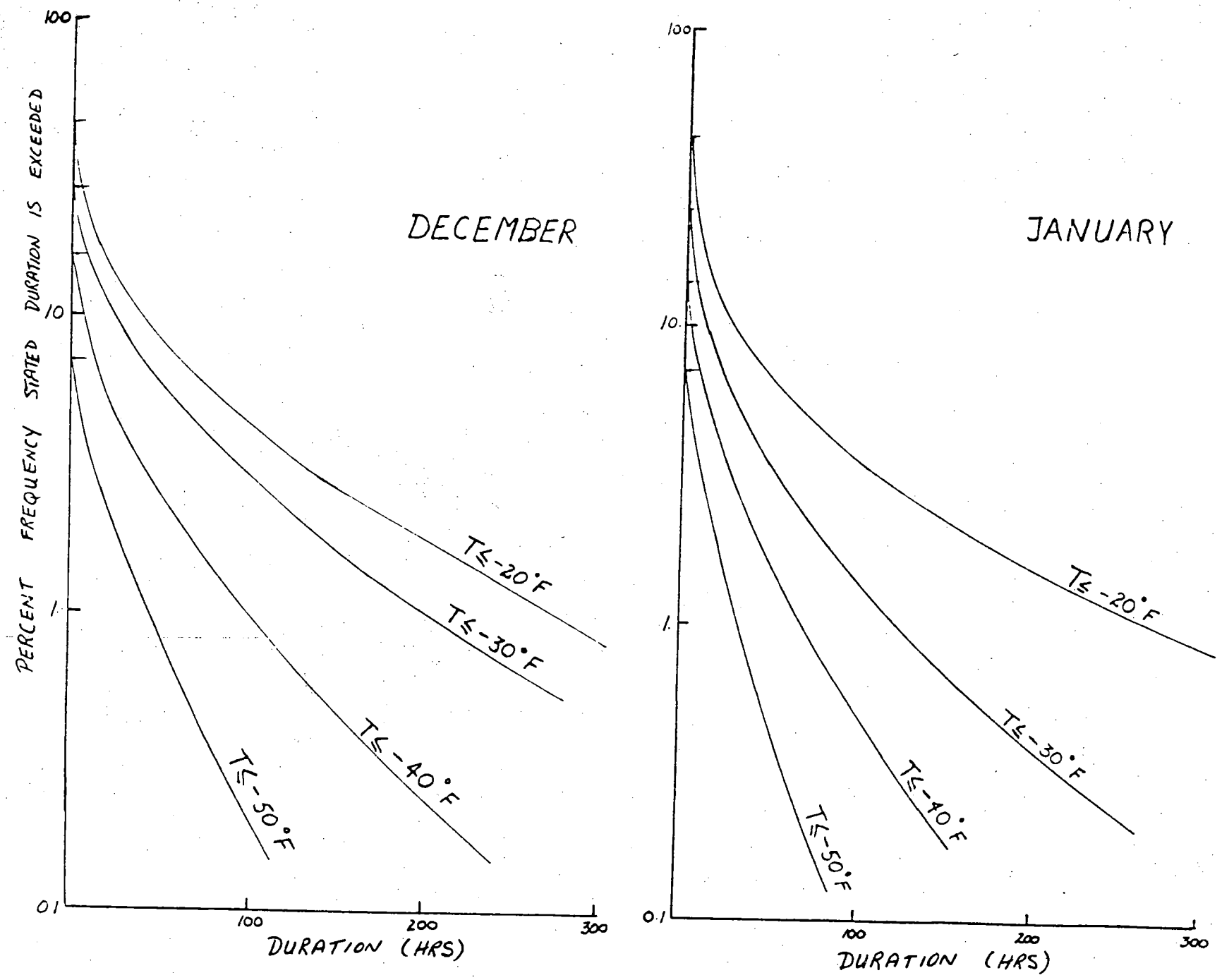


Figure 4. Frequency and Duration of cold spells during December/ January at Snag, Y.T.

	J	F	M	A	M	J	J	A	S	O	N	D
N	11	15	9	6	5	5	5	5	7	12	13	11
NE	14	15	11	9	13	14	13	14	16	11	12	13
E	4	3	2	2	2	2	1	2	2	2	2	3
SE	4	4	7	16	16	11	12	10	12	7	5	3
S	16	26	26	24	21	19	18	19	19	17	18	15
SW	4	6	18	12	13	15	16	12	11	7	5	7
W	1	3	4	6	6	5	6	5	6	5	4	3
NW	7	8	17	19	20	25	23	26	18	19	12	7
CALM	39	20	6	6	4	4	6	7	9	20	29	39
MEAN SPEED	1.2	1.6	2.5	3.4	3.7	3.6	3.0	3.0	2.6	2.2	1.4	1.1

Figure 5. Beaver Creek, Y.T. -- Percentage Frequency Wind Direction (and Calms) and Mean Wind Speed by Montha (April 1969 - August 1976)

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PROCEEDINGS OF THE AIR POLLUTION METEOROLOGY AND ENVIRONMENTAL ASSESSMENT WORKSHOP

held at the

Atmospheric Environment Service
Downsview, Ontario

MAY 7-10, 1979

Edited
by
R.V. Portelli
R.M. Hoff

PREFACE

This publication contains the proceedings of a workshop held by the Atmospheric Environment Service (AES) of Environment Canada, from May 7 to 10, 1979, on the topic of air pollution meteorology and environmental assessment. It was essentially an in-house AES workshop with about sixty participants representing AES Headquarters and its six Regional Offices.

The purpose of this workshop was to provide a forum for the exchange of information and ideas about air pollution meteorology and environmental assessment in Canada. Thirty-five papers were presented on a broad range of air quality activities and they appear in this volume with the post-presentation discussion and comments transcribed from tape recordings.

The contributions of the speakers, who devoted considerable time and effort in the preparation of their manuscripts for this publication, are gratefully acknowledged. The editors wish to express their appreciation to Mrs. C. Gauthier and K. Ford for their invaluable assistance in preparing a transcript of the tape recorded sessions and for typing the manuscripts. The artwork on the cover of these Proceedings was drawn by Dr. F. Fanaki and the graphics were done by Mr. B. Kiely.

R.V. Portelli and R.M. Hoff
Workshop Organizers and Editors

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WORKSHOP PROGRAM

MONDAY MAY 7, 1979

8:30	Registration	Foyer, AES
9:00	Welcome	A.E. Collin
9:15	Workshop Introduction	R.V. Portelli
SESSION 1:	AIR QUALITY IN THE CANADIAN ENVIRONMENT Chairman: B. Findlay	
9:30	Perspectives on Air Quality Assessments in Canada	R.E. Munn
10:00	AES HQ/Regional Responsibilities Re Air Quality	A.D. Christie
10:30	COFFEE	
10:45	Federal/Provincial Responsibilities Re Air Quality	H.E. Turner
11:15	Canada/U.S. Air Quality Relations	G.A. McBean
11:45	Environmental Impact Assessments in Canada: AES Policies and Procedures (E.A.R.P.)	H.L. Ferguson
12:15	LUNCH	
13:30	Regional Air Quality Activities, Problems and Future Outlooks:	
	1) Pacific Region 15m	S. Nikleva
	2) Western Region 15m	J. Kotylak
	3) Central Region 15m	H. Fraser
	4) Ontario Region 15m	R. Lawford
	5) Quebec Region 15m	G. Desautels
	6) Atlantic Region 15m	E. Brandon
14:45	Discussion Period on Regional Presentations	
15:00	COFFEE	
15:15	Panel/Plenary Discussion: AES HQ/Regional Liaison and How Best to Handle Air Quality Problems Panel Chairman: J.W.S. Young Panelists: R.E. Munn, A.D. Christie, H.L. Ferguson, S. Nikleva H. Fraser, R. Lawford.	
16:30	WINE & CHEESE RECEPTION	

TUESDAY MAY 8, 1979

SESSION II: FUNDAMENTALS OF DISPERSION ESTIMATES

Chairman: H.E. Turner

9:00	Theory & Application of Gaussian Dispersion Formulations	C.S. Matthias
10:00	COFFEE	
10:15	Plume Rise Estimates: Theory and Current Practice	F. Fanaki
11:30	Stability Classifications & Dispersion Coefficients	J.W.S. Young
12:15	LUNCH	
13:15	Dispersion Workshop: Problem Solving Session	C.S. Matthias F. Fanaki J.W.S. Young

WEDNESDAY MAY 9, 1979

SESSION III: PLUME DEPLETION AND TRANSFORMATIONS

Chairman: H.P. Sanderson

9:00	Wet and Dry Deposition of Pollutants	L.A. Barrie
9:30	Plume Chemical Transformations and Photo-Chemical Smog	H.A. Wiebe K. Anlauf
10:00	COFFEE	
10:15	SPECIAL PRESENTATION: "Extensive Data Sets of Diffuse-Sky Radiation for Atmospheric Models with Aerosols and Common Absorbing Gases"	J.V. Dave (IBM Scientific Centre, Palo Alto, California)

SESSION IV: AIR QUALITY COMPUTER MODELLING

Chairman: G.A. McBean

11:15	The Use of Computerized Gaussian Dispersion Models	J.L. Walmsley
12:15	LUNCH	

13:15	Implementation of User Models	R.V. Portelli J.W.S. Young
13:45	Flow Over Complex Terrain - Wind Field Models for Dispersion Calculations	P.A. Taylor
14:45	COFFEE	
15:00	Non-Gaussian Air Quality Models	J.D. Reid
16:00	Long-Range Transport: Trajectoring Modelling	M. Olson
16:30	Long-Range Transport: Concentration and Deposition Modelling	E.C. Voldner (Presented by M. Olson)

THURSDAY MAY 10, 1979

SESSION V: SPECIAL TOPICS

Chairman: L.A. Barrie

9:00	Regional & Global Air Pollution	D.M. Whelpdale
9:30	Stratospheric Air Pollution and Climate Change	W. Evans
10:00	Air Pollution Potential Studies	R.V. Portelli E. Wilson
10:30	COFFEE	
10:45	Urban Air Pollution Problems	M.M. Millan
11:15	Chemistry of Air Pollution	K. Anlauf P. Fellin
11:45	Observational Systems & Techniques	R. Hoff
12:15	LUNCH	
13:15	Sudbury Study	M.M. Millan
13:45	Nanticoke Study	R.V. Portelli
14:15	Alcan Pipeline Study	R.E. Mickle
14:45	Spruce Budworm Study	H. Newmann
15:15	COFFEE	
15:30	Atikokan Study	C.S. Matthias
16:00	LRTAP	H. C. Martin
16:30	Closing Remarks	R.V. Portelli

WELCOME

DR. A.E. COLLIN
Assistant Deputy Minister
Atmospheric Environment Service

I welcome the opportunity to speak here today because it gives me a good chance to meet with you and to talk briefly about what I think is happening in AES and in the meteorological services of the world. I will be speaking about the environmental realization developing throughout the world; in particular, that occurring in the services in industrialized nations.

On reviewing your agenda, I note that some forty experts will speak at this workshop. This is surely the most important and influential gathering of atmospheric specialists in Canada, and I am particularly delighted to see here scientists who are not only concerned about and working on environmental problems, but also knowledgeable about the national industrial relationships that pertain to those problems. I am convinced that in those industrialized nations which are concerned about their environment, the problem of the quality of the atmospheric invironment cannot be isolated from a consideration of the relevant industrial interrelationships. Therefore, what you say here in the days ahead is not merely a matter of passing scientific interest; rather, I would hope that it will have a bearing on what we do in Canada during the next few years. Since I do believe that the workshops held here periodically can contribute significantly to the body of knowledge in this country, my remarks will perhaps suggest how this contribution can be maximized.

In looking over the topics to which you will address yourselves, I think it is clear that your problem exists on several scales, which might be called "geopolitical scales", as well, scales of urgency, or what I would call "immediacy", apply.

The first of the "geopolitical scales" to consider is the international one. Within the last year or so, there has emerged a body of international thinking that is beginning to recognize that, in industrialized societies, a very clear relationship exists between the demands of exploitation for industrial needs and the pressures on the natural environment. I feel that the international community is now quite prepared to move with a certain amount of "immediacy" on those questions which are global in nature and which must obviously be considered by all nations concerned with their long-term industrial structure. These problems, as you all know, include: the rate of ozone depletion, the increasing concentration of carbon dioxide and other infra-red absorbing gases in the atmosphere, the increasing rate of deforestation - particularly of the tropical rain forests, and many others. It is interesting to note that these stresses on the quality or the composition of our atmosphere relate directly to projects which are designed to exploit or convert the earth's natural

resources. These projects are big and significant, both in the geographic and in the economic sense, and there is an ever-increasing pressure to accelerate the exploitation. However, we are gradually becoming alerted to some of the potential environmental impacts of such activities.

It seems to me that the major burden of responsibility for these impacts must be borne by those nations primarily responsible for the exploitation, that is, the industrialized nations of the world. These then are the countries that must adopt an ecological stance, by which I mean a stance that reflects a nation's responsibility to its atmosphere. In my opinion, however, it will not suffice to develop the capacity to speak with authority on matters dealing with the natural environment. Because of the inevitable interrelationships between that environment and industrial processes, the intellectual community must somehow equip itself to speak responsibly about both. I think, furthermore, that the major international bodies (e.g., ICSU, WMO, WHO, UNEP) are recognizing that it is mandatory to bring together an understanding of the natural environment with a knowledge of the industrial-economic infrastructure of the industrialized world. This integration is an urgent, demanding and also exciting, problem for the scientific community. It is this need for a new scientific cooperation that I see as the major pressure coming upon us internationally and, since it is obviously relevant to Canada, I hope that it will come into your discussions. It presents to a service such as ours a real challenge, and also a tremendous opportunity to help the world community to move forward in a very effective and spectacular way.

The second "geopolitical" scale to be considered is that of the bilateral responsibilities approach found, for example, between Western Europe and the Scandinavian countries, and also between the United States and Canada. In each of these there is an increasing recognition of the need to face jointly the problem of the transboundary transport of atmospheric pollution. This question has come to the forefront in the United States, with both the Senate and the House of Representatives taking the position that bilateral talks with Canada must take place on the full spectrum of problems arising from transboundary transport. In this case, the work of the environmental scientist is complicated by the "geopolitical" -- it certainly is both geographic <u>and</u> political -- nature of the problem. Discussions, which have <u>already</u> started, require cooperation and an exchange of information for the benefit of both countries. I foresee these discussions, which will be extremely complex, leading, after perhaps two or three years, to some formalized understanding or agreement between the two countries.

AES will obviously have a very real responsibility to contribute to these discussions as they evolve. The challenge here will be to work within the diplomatic framework, that is, to shape the management and the timing of a research program

within the process of a bilateral negotiation. This will be a demanding problem of scientific management because, as we are able to identify the research requirements that are, to us and to our American colleagues, obvious, we will have also to take into account the timeliness factor imposed upon us by the process of diplomatic negotiation. I expect that we will find urgencies thrust upon certain parts of our research programs. Although we will want to respond to the best of our ability scientifically, and within our best criteria for scientific management, we will also have to try to respond usefully for the requirements of the negotiation process. I think that our present feeling is that, rather than let the diplomatic process dictate to us the timing of our research program and thus perhaps create deadlines that could detract from scientific quality, we must start now to make a concerted effort in the management of our research programs to anticipate needs, so that our best judgement and guidance are available to the negotiation process. I thus foresee a delicate, yet interesting, interaction between this process of Canada-U.S. negotiation and discussion, and the management of research programs, not only in AES and in our Department, but also in other Departments and in the U.S. as well. Because of these new dimensions for management of research which are new to most of us, the next few years will be extremely interesting and challenging, though they will bring new, sometimes urgent, pressures for us to cope with.

The third relationship on my "geopolitical" scale is that within Canada. I am referring here to the provinces' interests in atmospheric pollution, the interaction between federal and provincial responsibilities in matters dealing with transboundary transport of pollutants, and the balance of one provincial urgency against another. In this last case, the problem of the acidification of lakes comes to mind: in Ontario, the public media at least are responding to the urgency of the situation: on the other hand, the Maritime interest in this problem is not quite the same. Thus, one of the difficulties that faces us, and will continue to do so, is this matter of interprovincial balance and federal-provincial reaction to urgencies perceived to be of different degrees by different jurisdictions. Furthermore, since the provinces have a clearly-defined responsibility for that chunk of the environment within their borders, it is clear that they are going to have to participate in our discussions with other countries on matters of atmospheric pollution. Thus, as we consider the bilateral (Canada-U.S.) discussions described earlier, it is obvious that there is a recognized role to be played by the provinces -- particularly, in this case, Ontario, not only because it has done a portion of the work, but also because it has very real concerns. This reasoning applies similarily to any other province which is able to contribute.

In the Canadian context, I would also hope that you would devote some thought to the Environmental Assessment and Review Process, which is a federal undertaking and one with which you are already familiar. EARP is requiring a very real, and expanding

responsibility and level of effort. As pressure mounts to increase the level of resources we apply to EARP, many questions arise: how are we going to find these resources; by what criteria are we going to apply them; where is the resource limit as far as EARP is concerned. I think over the next few days you will have to focus a little bit on our ability to respond.

Having considered to this point the questions of immediacy and political concern in regard to atmospheric pollution, I should like to turn my attention now more directly to AES. It is my strong feeling that the debate about headquarters or regional activity in AES must now be a thing of the past. I think that the pressure is on all our resources to contribute to Service or Departmental needs, because the fact is that there will not be two parallel Services in this country, and our Service covers the whole country. It is up to us to bring our resources and our wit together, with the unanimous objective of reflecting the scientific competence of the Service and of the Department. The debate about regional headquarters' configurations is a luxury to be deferred until all the other problems are solved. It does not apply right now.

In conclusion, I would like to share my thoughts on the direction AES will take over the next few years. The question of our priorities is really a choice between the limited range of the classic weather service and the broader spectrum of an environmental information body. I believe that there is a solid body of opinion within AES and in the Department which backs the wider option. In fact, it seems to me that we are already embarked upon this course, and that we have already assumed the increased responsibility of dealing with all those atmospheric-environmental concerns which are above and beyond the mere provision of weather information. I feel, therefore, that, in your discussions, you can take the question of AES' future direction as answered: we are well on our way to being an information service dealing with the atmospheric environment in its totality. What we are looking for now is the best application of our resources to achieve excellence in this broader role over the next few years.

WORKSHOP INTRODUCTION

R.V. PORTELLI

Air Quality Assessment Section

I would like now to give a brief introduction to this workshop and some background to it. As you can see, we're a fairly small group - a decision was made to maintain this workshop within the AES framework. There will be a few people giving presentations this week who are not from AES but the intent is to deal with problems with respect to air quality and environmental assessment within AES prior to dealing on the provincial and industrial level. I think this is an important time to do this, and in terms of the purpose for this workshop, as with any workshop, it is an opportunity or a forum for exchange of information, in this case with respect to air pollution meteorology and environmental assessment. That is in general terms, but in specific terms, there are a number of key points that should be noted. The first is that the workshop will hopefully enhance our understanding and appreciation of AES's role in the air quality field. As Dr. Collin has pointed out there are a number of issues which we should be addressing ourselves to. Technology transfer is another matter. We are here to transfer the technology from those with capability to those with need - the workshop proceedings will be put together so there will be a hard copy of this information available for use across the Service. It is also an opportunity to identify the environmental service requirements in the air quality field. We have representatives from each region here, and their experience from dealing directly with the provincial concerns, etc. should provide us with a wealth of information. Finally, in terms of purpose, it should stimulate, I hope, developments in the area of need; those identified now and many that have been identified. In some personal experiences, I have received calls for example from Hugh Fraser or Einar Einarsson from Winnipeg indicating that they require a capability to predict fog/ice fog generation from the incineration of moist refuse. These types of very specific applied problems need to be coped with and we need to have predictive capabilities for such situations.

The scope of the workshop and what it will cover is as follows: Day 1 is intended to be a general discussion on air quality and environmental assessment considerations in Canada, in terms of AES headquarters/regional, federal/provincial and Canada/U.S. relations and responsibilities. Days 2 and 3 are very specific in nature. They reflect the concerns expressed by most of the regional people during the preparation phase for the workshop. These two days will deal with the theory and techniques of making estimates of dispersion, depletion and transformation of pollutants followed by a session on air quality models - hopefully the most important models for application in Canada will be covered. The final day will deal with special

topics. It was identified as a special topics session since a broad range of air quality research activities (both general and very specific study areas) will be covered.

That, in my view, is the scope and purpose of this workshop. I have some personal feelings about our direction, and I would like to leave one with you. It's about the fact that we have a very large body of scientific knowledge available to us today in air pollution meteorology, which has been worked on the last 20 or 30 years - the entire field has been really developed only in the last 20 years or so. A lot of this knowledge has yet to be put into an applied mode which can be readily used or made readily available to those who need it (in Canada), whether it be people in the regions, the provinces or the industrial sector. Research is the most important aspect of the work of our branch (the Air Quality and Inter-Environmental Research Branch) and as you can see from the program, most of the people giving presentations are from this branch. However, I see that there is a strong need for us to take what we already know and plug it in, making it readily available. In doing this I am sure we will be able to identify new knowledge gaps where we should thrust our research efforts. That is to me one of the key purposes of having this workshop - to provide the impetus to carry-out this type of activity and to provide the services that are required in the field of air pollution meteorology and environmental assessments. That is all I have to say by way of introduction to the workshop.

PERSPECTIVES ON AIR QUALITY ASSESSMENTS IN CANADA

R. E. MUNN
Institute for Environmental Studies
University of Toronto

INTRODUCTION

The process of environmental impact assessment (EIA) began in Canada in the 1970s. Many other countries adopted rather similar procedures at about the same time, and today even large international agencies like the World Bank and UNDP require EIA determinations before approving funds for development. (See, for example, the World Bank publications listed in the references.) In retrospect, the creation of formal EIA procedures was a lagged response to the moods of the 1960s, and is out of phase with many of today's environmental concerns such as energy, resource depletion and climate change.

The successes and failures of the EIA process are still being debated. Nevertheless, a provisional Canadian perspective will be given in the next Section. This will lead to consideration of air quality assessments, whose most important feature is that they should be viewed in the context of total environmental management.

THE EIA PROCESS

There is no doubt that the EIA process has forced developers to consider environmental factors in their planning, and this has been beneficial. But the institutional and legal framework for EIAs was established before the scientific community knew how to prepare a useful decision-shaping document. A holistic view of the environment should encompass not only the physical and biological but also the socio-economic environment, e.g., life-style, the quality of life, beauty, employment, and the like. How can these various kinds of environments be described and compared?

There are three points of view on EIA content. On the one hand, there are traditionalists who believe that an EIA should concentrate on factors for which there are laws or regulations, e.g., emission standards, building codes, city by-laws, etc. The EIA is then a collection of results conveniently brought together in one publication. But if the air quality calculations have already been checked and approved by a control agency, why is there need for scrutiny by non-specialists at public hearings? And how are alternate sites to be ranked if all of them meet the control regulations?

It is for this reason that there is a second point of view on the contents of EIAs, viz., that they should concentrate on intangibles like the impact of the proposed development on life style, or on the bird populations of surrounding areas. These concerns are frequently voiced at public hearings.

A third point of view prevails in North America. This asserts that an EIA should be all-inclusive, averaging a thousand pages in length, with executive summaries sometimes exceeding 50 pages! In my view, the sheer mass of many EIAs is counterproductive, except as make-work programmes for those who prepare them and for thos who evaluate them. Schindler (1976) refers to the great EIA "boondoggle" arising from the creation of "a 'gray literature' so diffuse, so voluminous, and so limited in distribution that its conclusions and recommendations are never scrutinized by the scientific community at large." Schindler also suggests that "in general, the methods used are ancient descriptive textbook techniques, which do not reflect either the many scientific advances of the past decade or the problems unique to the study undertaken."

One of the earliest overviews of the institutional and scientific bases for EIAs was SCOPE 5 (Munn, 1975) which was drafted at a Workshop held at Victoria Harbour, Ontario in February 1974, and which proved to be rather successful, being translated into French, Japanese and Spanish. However, the book

has become rather dated, the number of countries requiring impact assessments having increased, as well as the literature on assessment methods. A Workshop was therefore held to prepare a second edition, which is now available (Munn, 1979). A few of the highlights are as follows.

(a) Affected parties

The citizens who gain and the citizens who lose from a proposed development should be identified in an EIA. These two groups are often separated in space and time, in incomes, in abilities to cope with impacts, and in the amount of public sympathy and political support that they can generate. In this connection, it is desirable to undertake EIAs at the policy level before commencing site-specific EIAs. For example, the general principles relating to the development of nuclear energy should be decided before EIAs are prepared for individual nuclear power stations. Solomon (1977) notes that at public hearings, criticism is often directed towards environmental policy (a government responsibility) as well as towards the project (the proponent's responsibility).

(b) Uncertainty

An EIA contains four kinds of uncertainty, due to:

(1) the natural variability of the environment, particularly the occurrence of rare events such as floods and earthquakes;

(2) inadequate understanding of the behaviour of the environment;

(3) inadequate data for the region being assessed;

(4) inadequate understanding/data on socio-economic factors.

Methods are available for predicting the first kind of uncertainty, e.g., return periods for flood control. The quantification of uncertainties of the other kinds is more difficult. When public disclosure of an EIA is required or when there is fear that an EIA may be "leaked" to the news media, the assessor sometimes uses one of the following protective mechanisms (Munn, 1977):

(1) the encyclopaedic approach: the assessor mentions every possible impact, even those that are very unlikely to occur (e.g., earthquakes and tornados);

(2) the circumspect approach: the assessor avoids mention of impacts that are controversial or could catch the attention of the news media.

Neither alternative is acceptable, and there is need for quantification of risks, or at least for comparisons amongst risks. But this is not an easy task, and the results are difficult to communicate to the public. Meteorologists are well aware of the problem of quantifying the probability that a tornado will occur, and of interpreting this to the news media.

(c) Adaptive strategies for EIAs

An EIA should be considered as an investigation into, rather than a determination of impacts. The present practice is that the EIA becomes of merely historical interest once a decision has been made on whether to proceed with the proposed development. A modest monitoring program may be established, but there is no regular overview to determine if the EIA predictions are going wrong. Perhaps the development has attracted secondary industry in unexpected ways, sometimes through a series of individually insignificant increments, or perhaps external influences such as unemployment, inflation or export trade patterns have

taken place. Holling (1978) and Munn (1979) have advocated a policy of adaptive impact assessment, in which an EIA is a continuing process and is to be periodically reviewed (perhaps every 3 years). One of the goals of an EIA should be to keep open as many options as possible.

(d) Socio-economic impacts

An EIA should include a brief discussion of socio-economic impacts, so that trade-offs with environmental concerns may be drawn to the attention of the public and decision-makers. Because socio-economic predictions contain many uncertainties, the analysis should be as simple as possible. For example, a helpful input would be a small table listing the most significant impacts in each column and affected parties in each row. Here it must be emphasized that an EIA should not be an advocate or an adversary document, but should strive for impartiality.

AIR QUALITY ASSESSMENTS

An air pollution assessment should be undertaken within the context of total environmental management, and should be a useful input to the decision-making process. Some other points that should be mentioned are as follows:

(a) Comparison of alternatives

Most EIAs now require that two or more alternative proposals, including that of rejecting the proposal, should be evaluated. In a recent application to construct a new uranium smelter, separate EIAs were prepared for sites near Port Hope, Sudbury and Blind River, and three public hearings were held. However, no comparisons were made, and in fact, all three sites were ultimately judged acceptable in terms of air quality standards and objectives. One might argue that

a comparison should have been undertaken, but what should be the basis for comparing the air pollution impacts at the three sites?

(b) The gap between theory and engineering practice

There is an information explosion in all areas of air pollution research: turbulent diffusion, long-range transport, atmospheric chemistry, deposition processes, dose-response relations, instrumentation and network design. Atmospheric scientists in the Toronto area are in the forefront of these developments, with capable people in AES, the Ontario Air Management Branch, the University of Toronto, York University, Ontario Hydro and the private firms (e.g., the MEP Company, James F. MacLaren, Ltd.). Without trying to be inclusive, at least some of the following papers will have a significant impact on air pollution research during the next decade:

L.A. Barrie (1978): An improved model of reversible SO_2-washout by rain. Atm. Env. 12, 407-412.

B.R. Kerman (1979): A similarity model for maximum ground-level concentration in a freely convective atmospheric boundary-layer. Boundary-Layer Meteorol. 16 (in press).

G.A. McBean and J.A. Elliott (1978): The energy budgets of the turbulent velocity components and the velocity-pressure gradient interactions. J. Atm. Sci. 35, 1890-1899.

M.M. Millan and R.M. Hoff (1978): Remote sensing of air pollutants by correlations spectroscopy - instrumental response characteristics. Atm. Env. 12, 853-864.

J.D. Reid (1979): Markov chain simulations of vertical dispersion in the neutral surface layer for surface and elevated releases. Boundary-Layer Meteorol. 16, 3-22.

A. Venkatrams (1978): Estimating the convective velocity scale for diffusion applications. Boundary-Layer Meteorol. 15, 447-452.

This is an impressive list indeed, demonstrating the existence of a "critical mass" of specialists. But the widening gap between theory and good engineering practice makes it difficult to apply any of the theories or results to the task of preparing an EIA for a power station or a smelter. This is not to suggest that the emphasis within AES Headquarters should be shifted towards applications. Far from it! However, consideration should be given to the problems of communications and technology transfer between the producers and the users of new knowledge.

The usual methods (training courses, workshops and educational publications) are of course helpful. In addition, however, short-term assignments (1-3 months) of Headquarters scientists to the Regions would keep them in touch with the many day-to-day problems that arise and that require action even with inadequate data and complex topography.

A further recommendation is that a manual be prepared on the topic: "The application of air pollution knowledge to the solution of engineering problems." This would require careful planning but the output could be an important practical book.*

(c) Non-technical summaries for public hearings

Assuming that the Eldorado public hearings are typical, many citizens are interested in development proposals and would like to participate in the discussions. However, they do not know how to phrase their questions, partly because the wording of EIAs is too technical. The air pollution scientist often refers to diffusion equations, the Pasquill C classification, or similar jargon.

* The AMS book, "Lectures on Air Pollution and Environmental Impact Assessment"(1975) is a valuable reference but is not of much use with respect to preparing an EIA.

Other examples could be cited but they would not have the impact on a meteorological audience as would the following biological illustration, taken from an EIA relating to the expansion of Vancouver airport:

> "Measurement of functional chlorophyll in the sediment of the Fraser River delta in January to March, 1974 gave a range of values from 4 to 225 mg chla/m^2, with a mean of 70 mg/m^2. These values are similar to those obtained during the summer of 1972 and to values of phytoplankton chlorophyll a obtained in moderately to highly productive oceanic and coastal waters."

Efford (1975) comments that this is "a particularly useless statement when it remains without interpretation or explanation."

(d) <u>The quantification of uncertainty</u>

Twenty years ago an air pollution assessment was often limited to a single design case: steady winds and a moderate surface-based inversion. Today the assessment includes expected frequency distributions of concentrations for various grid points and averaging times, so that estimates of the probabilities of excedances of air quality standards can be calculated. However, the analysis contains many implicit uncertainties, and there is rarely an attempt to make them explicit, or to investigate their total impact on the final estimates of downwind concentrations. In most cases, for example, the wind rose used will not be exactly the same as that at the site, nor will the wind climatology for the next 30 years be the same as it was over the last 30. Although this is not likely to affect the analysis in a major way, the EIA should include a sensitivity analysis to quantify uncertainties in at least an empirical way. Studies like that by

Walmsley and Bagg (1978) should be encouraged, the goal being to develop a rationale and general guidelines. Present EIA practice is to use climate data from the nearest observing station, with an implied shrug of the shoulders. This approach is usually acceptable to other members of the peer group but is rather unsettling to the non-specialist.

(e) EIAs for Canadian-sponsored projects in other countries

In the United States there are new regulations requiring the preparation of EIAs before funding of overseas projects can be approved. This is a welcome step forward that should be followed in Canada. It would seem reasonable, for example, that AES should have a role to play in the determination of the environmental impacts of proposed overseas developments funded by CIDA.

CONCLUSION

Environmental research is concerned with describing, explaining and predicting the behaviour of environmental phenomena or processes. Environmental research is usually open-ended, no problem ever being completely solved.

Environmental engineering is the application of existing knowledge to the solution of real problems under conditions that are never as simple as those in the idealized research models. The outputs will be scrutinized by other engineers, e.g., building inspectors, air pollution control officers, etc.

An EIA assessment falls into the environmental engineering category but is broader in scope, with many interconnecting links. In addition, it will usually become a public document, and may be attacked on non-technical grounds.

This brief presentation has pointed out some deficiencies in present EIA practices and has made some suggestions. There is no doubt that the EIA process is here to stay and that scientists have a duty to seek to improve the EIA system as well

as the technical content.

The next major advances will be in the intergovernmental area, where institutional and scientific frameworks for intergovernmental and global EIAs are still largely missing. A good example is to be found in the climate impact assessment program of the WMO, which is now in the formative stage.

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DISCUSSION/COMMENTS

R.M. HOFF: Regarding this technique of an adaptive EIA do you think that industry will be willing to buy an adaptive EIA strategy where they would have to go back every two or three years to an EIA proceding? Wouldn't they be happier having the whole thing over and done with in an EIA?

R.E. MUNN: Oh yes, I'm sure they would, but usually they don't develop as was expected. For example, Douglas Point; it wasn't called an EIA in those days, but there was a group here at AES that did some impact assessment studies in the 60's, and it was quite clear that the safety and all the control regulations were quite satisfactory for the emissions, and all the proposals at that time, but a little later on they built a chimney putting hydrogen sulphate in the atmosphere, and there were bad odors and all kinds of problems, and the local citizens were alarmed and they were mixed up as to whether it was the bad smells or the radioactivity and as that Douglas Point complex developed, it, in my view, would have been extremely useful for continuing process. I know it means more work for people like you, but I think it would have been very helpful indeed.

A.D. CHRISTIE: For clarification on that, Ted, what you are suggesting, then, is that only the new part of a plant going in would be liable to this adaptive EIA, not the part that had been done before?

R.E. MUNN: No, I'm not suggesting that, because the world climate might change, for example, so that all the calculations are no longer valid. There should be some attempt from time to time to look back at these impact assessment statements that were produced. Air pollution is a poor example because people like Lou Shenfield got the situation under control, and he had a few more precipitators and so on, but in the more general case of the socio-economic or biological implications, I think it's important that these things be checked because the predictions are so uncertain.

AES HQ/REGIONAL RESPONSIBILITIES RE AIR QUALITY

A.D. CHRISTIE
AIR QUALITY AND INTER-ENVIRONMENTAL RESEARCH BRANCH

INTRODUCTION

In recent years problems involving a wide spectrum of environmental issues that need meteorological 'know how' have come to the fore across Canada. These have led us progressively farther from what we might have called 'bread and butter' weather forecasting into areas of ecological impact. The RD, whose responsibility it is, to assess and respond to these needs has found it difficult to find resources and expertise, even within his SSU to provide more than ad hoc answers.

How can the situation be improved particularly in a period of severe resource constraints?

In my view we already have the basic requirements for a much improved system for dealing with many environmental matters involving air quality by introducing consistency, efficiency and economy, provided we deal with the system as an AES problem rather than one faced by each Region independently.

The blueprint for such a system can not be cast in stone, it must be evolving, but in a manner acceptable to all parties. It includes research and development, training and application to user problems and I'd like to clarify for you how I see this system as best working.

PROBLEM IDENTIFICATION AND RESPONSE

It is the function of the RD to provide services to users consistent with the AES mandate. Problems posed may be solvable directly using established routines, or may require the application of advanced methods or technology not currently available in the Region resulting in an ad hoc or a 'put off' response. In the case of the former no comment is necessary but for the latter type of question we should try to continually

improve our capacity to respond in a timely and accurate way.

How do we respond to the more esoteric questions? If it looks like a 'one shot' request the SSU must respond as best he can within the time limit imposed, and should feel no reticence about drawing from what pool of expertise exists in Downsview. It would be poor business sense to try to replicate all specialists in each Region when the environmental sciences are becoming progressively more interdisciplinary.

The availability of Downsview staff to provide consultant advice should be a matter of common consent. A prime role of HQ R&D staff, however, should be to help provide methods (including computer software, its documentation and training in its use) to all Regional offices to permit timely solution of a variety of air quality problems.

If we accept that thesis in principal, we must still agree on the problems to be solved, and the degree of sophistication needed. Ultimately time and money are the main constraints.

If a question can be identified as of a kind likely to be repeated, and which could be amenable to a general type of solution though one does not currently exist; that question may well be suggested to AQRB as one for solution by them. The solution preferably to be in the form of a documented software package compatible with Regional computers.

In the event that the problem is one of considerable difficulty requiring 'custom' combination of a few subroutines to deal with various aspects of a complex problem, we would prefer that the problem and the necessary data be supplied to the Downsview Environmental Impact Group who should return the solution.

With more routine problems where the solution has been tested and training provided to Regional SSU staff, AQRB staff need only be consulted at the discretion of the SSU's or in the case of some unusual difficulty arising.

As noted above specialized air quality training should be given increased emphasis. It is important that the Regional staff understand both current capabilities and current limitations in air quality diagnostic and predictive capabilities.

I would like to see the training evolve along two lines -- conventional training workshops such as the one we are beginning here today and 'on the job training' where SSU staff can be assigned for short periods to AQRB for familiarization with the Downsview operations and to participate in special projects.

Finally there is the matter of appropriate baseline data for environmental impact assessment. In order to use any model effectively representative data sets must be available. In general there is insufficient lead time to obtain the appropriate site specific information at the time of a review. We feel that data sets characteristic of various scenarios of terrain and climate must be obtained and modified with what limited site specific data are available, in order to minimize the data restrictions. Such general baseline data sets should have application to various regions and it may be worth considering the coordination of staff from one or more Region together with the special observations group from Downsview during intensive study periods in representative locales to build up such data sets.

CONCLUSIONS

In view of the resource constraints in the Service and the increasing requirements for objective environmental assessments, economic use of the available staff in the Regions and at Downsview is mandatory.

The proposals in my presentation have dealt with problem identification, techniques development and implementation,

workshop and familiarization training, and acquisition of representative baseline data sets involving a cooperative approach between the SSU's and AQRB. Hopefully these will give some food for thought during the Workshop and provide a focus for increased cooperation when you return to your respective SSU's.

DISCUSSION/COMMENTS

J.D. REID: Maybe Ted (Munn) would like to have a go at this one, too. You mentioned some figures with regard to the sorts of accuracy of assessment: 10%, 100%. Ted made some statements about how useful assessments could be. Is any number, not matter how accurate, better than no number at all?

A.D. CHRISTIE: I think this is the case, but it may be that what I am referring to here isn't that the same accuracy is necessary of every prediction. To take the current situation for example, where we had the nuclear accident down at Three Mile Island. The kind of questions that were asked there weren't really a question of what is the concentration of a given radio-isotope going to be at such and such a spot, the kind of question that was asked is "Do you know where the radioactive cloud is going to move?" Now if we can say that the position on the trajectory is going to be within 20 miles of the position that we predict on either side, that gives some kind of information for that problem. If someone is trying to design an evacuation strategy, that may be all the accuracy they need. They may not need to know concentrations, if they know it's going to be a matter of 10% of the lethal dose, they may want to get out of there whether its going to be 10% or 100%. This is the kind of accuracy that I am talking about. Each problem has its own specific requirements, and we shouldn't be trying to overpredict the situation; what we should be interested in doing is saying we can predict to this amount of accuracy, is that useful to you? Can it be used?

J.D. REID: Ok you said now you can predict the trajectory and you can predict within 10%. Now suppose you can only predict within two orders of magnitude; should you be giving an answer at all? And I'd like to get Ted (Munn)'s input on what sort of a guideline could you give about when it's useful to start making predictions and when should you say frankly the science isn't developed?

R.E. MUNN: The first question is to make estimates of the range, and that's never done. For example, on the Blind River uranium smelting study, and Blind River is on the north shore of the north channel between the Manitoulin Island and the mainland. Anyway, Blind River now is a very complicated diffusion analysis, and they use the winds from Gore Bay, which is on the south side of the channel, and the public, there were 300 or 400 people there, and they were unsettled, and they wanted to know of course if the Gore Bay winds were the same as the Blind River, and nobody really knew the answer, and so it was left up in the air. So that's the first question, is to know what the range is, and that's hardly ever done in an impact assessment. The second question depends on the user. I think he's got to tell you whether it's useful. You can't tell him

whether it's useful, and it may be that he has got so many safety factors that as long as you're within that two orders of magnitude he is still alright. It may be that things are very critical, and that the user requirement may be different on the one side of the distribution than on the other side, so it's really up to him to tell the assessor what is important for him.

A.D. CHRISTIE: I think that illustrates what I was talking about, is the necessity of having some kind of interaction between the user and the developer of a system. You certainly have that in consultant companies, and the problem is in many instances, with us in Downsview here, is that we don't have the direct interface. The regional offices have the direct interface, and we have to take advice from them on many occasions, how they interpret what the user's needs are. This is an important aspect of the interchange that I see between the regions and ourselves.

R.M. HOFF: Following up on John's question, I was just in a situation where scientific opinion was being used by a government to make a decision on evacuation of people. How far is AES willing to go in backing up a scientific decision? There's going to be a considerable amount of heat if you make a wrong decision, say in a Harrisburg situation, brought upon AES. Do you feel that we are going to be able to stand up to that kind of criticism, or will the end result be, after being burnt once, let's say, we stop making those kinds of inputs to political decisions affecting the environment.

A.D. CHRISTIE: My reaction would be that we can't avoid facing up to making these decisions. That really is what this service is here for. We are basically a service organization, and if we are asked to provide information, we provide it to the limits of our capability. We try and hedge it in terms of explaining what the limitations of our knowledge are, but we have to give the answer. That's the way I see it.

G. DESAUTELS: When you were talking about the regional staff, the developmental education group and the supporting research group working together to end really at doing our job at AES, were talking about or did you have in mind some kind of formal group or coordinating group?

A.D. CHRISTIE: I would like to see this. As I say, this is a blueprint for what I would like to see happen. It's the kind of thing that we should be discussing here. I would see this meeting as being an appropriate place, whether you have a small task group from the regions involved in the planning process, you've got to realize that having our resource constraints as well as yours, this really means that in the planning process, the planning of any kind of coordinated activity has to go on early on in the planning process. It's all very well to say that we need something in a hurry. We've all got this problem where we have constraints put on us in a hurry, but what I would like to see is some sort of coordinated group who were active in the programming, in the planning process, so that they could have not only input into headquarters, into Downsview program planning and financial planning, but obviously have input to the regions involved as well. If we are going to have any kind of coordinated activities that involve more than one region, as well as a region and Downsview, there's obviously got to be some prior planning if we are going to run this type of thing effectively. I would say that at this stage, I haven't got any firm idea of what this kind of interface should be, but I see the need for it, and that's part of what I think this meeting is for, is to try and come up

with some possibilities that can be considered by senior management.

R. LAWFORD: What role does the Canadian Climate Centre play in your Venn diagram there? Some of the regions, particularly the Western region have a fair bit of interaction for development in the Northwest Territories in environmental assessment use. Do you see a role for them?

A.D. CHRISTIE: Yes, to the same extent that I see a role for us. Environmental impact review is not uniquely an air quality aspect. There is an air quality aspect of all environmental impact reviews; in fact I think it is probably premature for me to go into this, because Howard (Ferguson), is giving a talk on it later this morning, and it's essentially the paper that he's presenting to AMC at the moment, so I think that he is probably the person with whom you should discuss this kind of coordination. At the moment there is something that is foreseen in terms of coordination between any Downsview component and the regions on an environmental impact.

R. LAWFORD: So your Venn diagram is just air quality.

A.D. CHRISTIE: Yes, I really don't think in terms of this as representing air quality or anything else. I mentioned the overlap with the regions indicate the air quality aspect of it, but this isn't unique. I mean you can consider a series of strata in there that represent different headquarters' capabilities.

H. FRASER: Do you have any specific thoughts or plans to improve technology transfer which you would like to share with us that this time?

A.D. CHRISTIE: Maybe Ron Portelli could respond to that question.

R.V. PORTELLI: Yes, I have some views on that which I hope will be put into action in near future. This workshop is in fact one of the first steps that we're taking towards the development of mechanisms for technology transfer. We've already developed some air quality application models for user purposes. Some of these have been documented in user guide form, and we have had some response on that - they have yet to be put into wide usage. In terms of the all-out effort that we could make, in terms of transferring technology, we need to take as I said earlier, information which we already have and apply it; I think there is a lot of information that can be put into a techniques development document, which could then be used for a number of various activities. For example, the Harrisburg incident, or even down to the smaller scale problems such as I mentioned before on the ice fog generation at airports. There, I believe we have the capability; my plan would be if we had the resources, to put this together in a package which would continue to be developed through time and provide regional people with what they require. More than that I can't really say.

A.D. CHRISTIE: Obviously this has got to be an ongoing process. You don't get something overnight, as you are probably well aware by now. I think really what we are saying is that the will is there, and where there's a will there's a way in the foreseeable future. We really should discuss what are the most important things to get on a short time scale, and how we can get them. We are looking to the idea of transfer; I think again the Harrisburg situation was mentioned - the trajectory model that was used for that is going to become accessible to Field Services (Directorate) for their use should any other

emergency of this type turn up at Bruce or Pickering (Nuclear Facilities) or any of the other areas of that kind. So I think the difference is that what we really should be looking at is when we have developed a technique, and we should know what it can be applied to, identify it, document it, and make it available. That's the path that I would like to see us follow. Now, we'll see how things go.

FEDERAL/PROVINCIAL RESPONSIBILITIES WITH RESPECT TO AIR QUALITY

H.E. TURNER

Atmospheric Dispersion Division

INTRODUCTION

The primary use of air as a resource is to support life. It also has many secondary uses, perhaps dominated by its role as a receptacle for waste residuals of human activity. In the 1960's there arose a strong public awareness of a growing conflict between these primary and secondary needs and the result was a demand for government at all levels to take appropriate action to protect air quality in the public interest. In our federal system, however, such action must take appropriate recognition of legislative authority and, in attempting to do so, one enters the "jurisdictional haze" that envelops environmental management in Canada.

The jurisdictional problem arises from the particular nature of our Canadian constitution and this aspect will be considered first. Next, the constitutional impact upon environmental authority will be discussed and the paper will conclude with a consideration of just what the appropriate federal/provincial responsibility is.

THE CONSTITUTIONAL FRAMEWORK FOR ENVIRONMENTAL MANAGEMENT IN CANADA

Two problems immediately arise when one attempts to investigate the constitutional basis for environmental management in Canada. In the first place, our constitution is to a large extent "unwritten" and, second, what is written is very much open to interpretation. These points are considered below in reverse order.

For Canada, the British North America (BNA) Act serves as the written constitution. This Act, however, does not pretend to be a comprehensive document such as, for example, the United States constitution and there is no attempt to cover all the

essentials of government within a limited number of carefully worded sections. In fact, there are very many vital things about the government of Canada and her provinces which are not even hinted at in the BNA Act and even those matters which are dealt with in some detail are frequently stated in such a way that they become ambiguous and misleading.

What is termed the "unwritten" constitution is equally as important as the BNA Act. It consists of principles of the common law as accepted by the courts, certain British and Canadian acts of parliament and orders-in-council, judicial interpretations of both the written consitution and other laws, rules and privileges of parliament, established customs and usages and many other habitual and informal methods of government which have grown up over a long period of years. All of these, many of them (despite the misleading term "unwritten") committed to writing while others exist in a more intangible and elusive form, exert a powerful influence upon constitutional practice. In terms of the constitutional basis for environmental management, however, it appears that judicial interpretations of the written constitution are the most significant "unwritten" factors.

Inasmuch as the purpose of the BNA Act was to create a federation, the provisions dealing with national and provincial powers and relationships comprise a very large and important section of the written constitution. In particular, the Act gives some thirty specific powers to the federal parliament and another twenty or so explicitly to the provincial legislatures. (As a background to further discussion, Table I indicates the distribution of those powers which might have a bearing on environmental jurisdiction). It is these very provisions, however, which have given rise to disputes and uncertainties and have furnished the material for the seemingly constant struggle between rival national and local authorities. Moreover, since these same provisions appear in a formally rigid constitution, they have not been readily amendable. In order to gain further insight into federal/provincial responsibilities, then, it becomes necessary to consider the results of constitutional

interpretation by the courts.

There is still some debate as to whether the deliberate plan in creating the Dominion of Canada was to form a federation of a highly centralized or decentralized kind. A strong body of evidence exists, however, to support the former interpretation and a powerful part of this evidence concerns the concept of "residue" powers. In any federal constitution, a complete accounting of powers granted to central and local governments is impossible and it is therefore customary to insert a blanket clause where all unallotted or residue powers are given to one party or the other. Initial interpretations of the BNA Act accepted the first federal power listed in Table I as the residue power, i.e. provincial powers were to be explicitly as listed, the federal "peace, order and good government" clause covered everything else and other listed federal powers were considered to be simply examples of the jurisdictional residue.

In spite of this fairly auspicious start, the distribution of powers has rarely, if ever, had the cordial and united approval of the provinces. The result has been a continuing federal/provincial tug-of-war which commenced with a significant trend towards decentralization in the latter part of the nineteenth century. At that time, judicial interpretation of the BNA Act set precedents whereby it was considered that nearly all legislation would impact in some way upon "property and civil rights" (which would be especially true for environmental legislation), a provincial jurisdiction (Table I). As a consequence it was considered that federal powers were as explicitly given in the Act, that the "peace, order and good government" clause was just a comprehensive emergency power to be used in times of dire necessity or grave national peril, and that the residual powers lay with the provinces under the cover of property and civil rights.

During the period 1914-1960, which encompassed the Depression and two World Wars, the jurisdictional tendency reversed towards centralization and the correlation of this tendency with hard times is real. This resulted in a softening of the

interpretation of the "peace, order and good government" clause from purely emergency powers to legislation which must, from its inherent nature, be the concern of the nation as a whole. On the other hand, over the last two decades, the general trend seems to have again been to give more power to the provinces although this seems to have been more a matter of political negotiation than of legal decision. It was at this stage of constitutional uncertainty, then, that concern for the development and application of environmental strategies arose.

JURISDICTIONAL PROBLEMS IN ENVIRONMENTAL MANAGEMENT

Comprehensive environmental management was not, of course, one of the considerations of those who framed the constitution. In view of both this and the enormous scope and complexity of the subject matter, any attempt to determine the precise fields of responsibility was bound to run into problems. Several of the major difficulties are briefly described below.

(a) Jurisdictional Interpretation: - Problems with the interpretation of constitutionally valid legislative powers have already been alluded to above but perhaps an example is in order here. Recently, a trucking company and a cement plant were charged under the noise provisions of the Ontario Environmental Protection Act. The presiding judge, however, held that the protection and conservation of the environment was a matter of national concern in such a sense as to bring it within the exclusive legislative domain of the Dominion Parliament. Had this decision not been overruled by the Supreme Court of Ontario, its effect could have been to impose upon the federal government the responsibility for enacting municipal noise, litter, and other like by-laws. Such a task is hardly one which even the most ardent federalist would relish.

(b) Legislation vs. Ownership: A second important key to understanding jurisdictional problems with respect to environmental management in Canada is an awareness that the proprietary or ownership rights of each government with respect to the environment differ substantially from their legislative or law-

making rights. This could lead to potential conflicts between environmental legislation and civil law since most natural resources lying within provincial boundaries that are not privately owned belong to the province. This would include land, minerals, timber, wildlife and, through the common law doctrine of "riparian rights", water and, to some extent at least, air space. A good example of a potential problem area in this context concerns fisheries where the federal government has legislative powers with respect to "sea-coast and inland" fisheries while "non-tidal" fisheries are provincially owned.

(c) Jurisdictional Overlaps: In many cases, the legislative powers of the federal and provincial governments overlap with the result that either may make laws on the same subject. This is not in itself a problem except that there can be little co-ordination between what is done federally and what is done provincially. Consider the case of an ocean freighter dumping bunker oil in Toronto harbour. Certainly this is of greater concern to residents of Toronto than those of other parts of Canada. Nevertheless, the legislative jurisdiction over this activity held by the federal government prevails as a matter pertaining to shipping and navigable waters even though, on the face of the situation, the provincial government water laws might appear more logically applicable. This overlap problem has also been viewed as an excuse for inaction by both levels of government.

(d) Constitutional Rigidity: - An important implied constitutional limitation upon the delegation of legislative powers arises from the nature of the constitution itself, namely, that in all likelihood neither Dominion nor province can delegate its powers to the other. Such a change would require, in effect an amendment to the BNA Act. This is by no means a theoretical point. Both the federal government and the provinces have time and time again run into difficulties because the jurisdiction of the one alone was not complete enough to enable it to regulate adequately an entire operation.

FEDERAL/PROVINCIAL RESPONSIBILITIES

At the outset, it would appear that the provinces could claim paramountcy on all land aspects of environmental policy. They could also claim responsibility with respect to air and water pollution control, either as a result of the "riparian rights" doctrine or on the grounds that pollution control is truly a local matter within the province. Specifically, in the field of air pollution, the provincial power over land and matters of local concern has been interpreted as giving the provinces the prerogative in stationary-source pollution control.

On the other hand, the federal government has highly relevant legislative powers. The greatest of these include the "navigation and shipping", "fisheries" and "criminal law" powers as well as the jurisdiction over "works and undertakings" connecting provinces or extending beyond provincial limits. Another strong federal influence can be exerted through its spending powers which permit the provision of grants-in-aid with environmental strings attached. We thus have the situation that, at the federal level alone, the list of legislative acts relevant to measures for environment protection includes some seventy titles. A similar compilation of provincial legislation would lead to the same impressive results.

In the 1960's, then, the question was, "Should the federal government be involved in any comprehensive way in the management of our atmospheric resources?" The reasons which led to an affirmative answer probably don't require any argument in this forum. The very complexity of environmental problems, where pathways and impacts can be widespread and where there exists strong interrelationships between environmental, technical, biological and economic considerations, requires a broad-based approach to environmental management. From the standpoint of social efficiency, then, one can see the desirability of a federal leadership role in this field. This conclusion, however, begged a second question - "Could the federal government be involved?" - given the fact that the majority of the sources of air pollution came under provincial legislative authority. Any

new federal legislation would have to be clearly within federal constitutional powers or have the complete agreement of all ten provinces. It became clearly apparent that the appropriate federal/provincial responsibilities can be summed up in two words - the same responsibility for each - to co-operate. There is no other effective way in our federal system.

This co-operative approach on the part of the federal government is quite apparent in the Clean Air Act of 1971. Its objectives mark out a complementary supportive role at the federal level which relies upon mechanisms of co-operation and co-ordination such as the Federal/Provincial Committee on Air Pollution and individual Canada/Province Environmental Accords. Although problems have been encountered in this co-operative venture (e.g. Environmental Accords have not yet been signed with three provinces), the application of important new concepts in environmental management such as the preventative approach (e.g. the Environmental Contaminants Act and the Environmental Assessment and Review Process) requires that every attempt be made to attain agreement.

Environmental policy should be developed in an atmosphere of co-operation between all levels of government as well as industry and the public. As long as governments and their agencies operate within small circles, jealously guarding what they view as their jurisdictional and administrative rights, little effective progress can be made.

TABLE I

CONSTITUTIONAL DISTRIBUTION OF POWERS RELEVANT TO ENVIRONMENTAL MANAGEMENT

Federal Parliament

- Make laws for the peace, order and good government of Canada re those matters not explicitly given to the provinces
- Regulation of trade and commerce
- Raising money by any mode or system of taxation
- Navigation & shipping
- Fisheries
- Criminal Law
- Interprovincial transport
- Public Debt
- Foreign treaties

Provincial Legislature

- All matters of a merely local or private nature within the province
- Local works and undertakings
- Local licenses and incorporation of companies with provincial objects
- Direct taxation
- Property and civil rights

CONCURRENT POWERS

- Agriculture

DISCUSSION/COMMENTS

R.V. PORTELLI: We are all aware that there is a movement afoot to drive toward an agreement or treaty with the U.S. and I believe Gord McBean will discuss some of these implications later, but with respect to your study, and in relation to the provincial government initiating treaties on their own behalf with the U.S., could you elaborate a little bit on that, and have there been any actually signed, and are there any in progess now that you are aware of?

H.E. TURNER: The question of treaty rights in the assignment of legislative powers under the British North America Act lies with the federal government, but it's worded such that this pertains only to treaties, which in fact involve the foreign power with the British Empire. Now, Canada, standing as a nation alone, then, its treaty rights are in fact not mentioned in the British North America Act, so that yes, the provinces have a right to negotiate a foreign treaty under those terms. There's nothing to stop them. What would happen I think in this case, though, is that there would be a judicial review of the content of this treaty, to see whether in fact it is just a provincial concern, or whether in fact it ought to be a national concern. I am not aware of any existing provincial foreign treaties. That's not to say they don't exist. Certainly on the air side they don't. Now on the water side I'm not sure, and I can't speak to that, but I know there was some consideration at one time in the Province of Saskatchewan signing a treaty with the United States, which in fact was prompted by Saskatchewan Power Corporation, the Poplar River situation, where Saskatchewan Power had a stack emitting SO_2 close to the border, and I heard some talk of this, but I don't think anything ever came of it.

R.E. MUNN: As an amusing historical footnote, when the Clean Air Act was being debated in the House of Commons, an Honourable Member asked the Honourable Jack Davis whether the Clean Air Act covered odours and Jack Davis said "No, bad smells were the responsibilities of the provinces."

CANADA/U.S. AIR QUALITY RELATIONS

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INTRODUCTION

For many years air pollution was considered primarily within the context of the urban environment. In some cases, notably in the Detroit-Windsor area, this has resulted in pollution from one country effecting another, but, generally, air pollution could be considered as an internal problem for each nation to deal with as it chose. With the escalating loading of our air environment it has become painfully apparent that air pollution can no longer be considered in a limited geographical context. The long-range transport of air pollutants (LRTAP) over distances of hundreds to thousands of kilometres has been identified as a major environmental concern in both Europe and eastern North America. At the same time, environmental concerns have increased so that localized problems arising from trans-boundary flux of air pollutants have become contentious.

In the following, the historical development of Canada/U.S. air quality relations will be reviewed. Then reference will be made to the multinational forums before describing the present situation.

HISTORICAL BACKGROUND

The first significant agreement between Canada and the United States regarding transboundary pollution was the International Boundary Waters Treaty of 1909. This treaty established the International Joint Commission (IJC) to deal with matters of difference between the Governments and specified a number of agreements regarding boundary waters. In Article IV, which deals mainly with effects on water levels, it states:

> "It is further agreed that the waters herein defined as boundary waters and waters flowing across the boundary shall not be polluted on either side to the injury of health or property on the other."

The IJC has been involved in a number of transboundary water pollution problems, originating with a reference on pollution of boundary waters in 1912 and continuing to the present activities under the Great Lakes Water Quality Agreement. It is interesting to note that the recommendations of the 1912 report were not implemented. More recent recommendations have been more successful.

The next major event was investigation of damages to vegetation in parts of Washington State by sulphur dioxide emitted by the smelters of the Cominco smelter in Trail, B.C. The IJC completed a report in 1928 but it was not accepted by the U.S. In 1935 the two Governments set up an Arbitral Tribunal to determine whether or not the smelter was causing the damage and, if so, whether compensation should be paid and to determine whether or not an operating regime could be developed which would prevent further damage. It is indicative of the legal and technical difficulties involved in that it was not until 1941 that the Tribunal reached agreement and the extensive meteorological studies continued until 1944 (Hewson and Gill, 1944). The legal principle established by the Tribunal was that:

> "... no State has the right to use or to permit the use of its territory in such a manner as to cause injury in or to the territory of another or the properties or persons therein, when the case is of serious consequence and the injury is established by clear and convincing evidence."

The difficulty with the general application of this principal is that it is difficult to establish injury "by clear and convincing evidence", particularly in the case of LRTAP.

Another area of IJC involvement regarding transboundary

air pollution problems has been in the Detroit/Windsor and Port Huron/Sarnia areas. This problem was recognized in 1934 and a series of actions lead eventually to the signing in 1974, of the Memorandum of Understanding between the State of Michigan and the Province of Ontario. This Memorandum pledged the two governments to co-operate in implementing the air quality objectives recommended by the IJC. At the request of the federal governments the IJC established the International Michigan/Ontario Air Pollution Board in 1975.

Although most of the IJC activities have been associated with water problems, several, such as the Upper Lakes Reference and Pollution from Land Use Reference, included investigation of atmospheric loadings of boundary waters. The importance of atmospheric loadings of the Great Lakes was noted in 1978 Great Lakes Water Quality Agreement. Under that agreement the Governments agreed to consult in cases where studies under the GLWQA identify significant loadings from atmospheric sources.

During the past year or more, concern has been expressed in the United States about the potential environmental effects of new thermal generating stations being proposed for Atikokan, Ontario and East Poplar River, Saskatchewan. In these cases, there have been bilateral consultations involving the appropriate states and provinces, as well as the federal governments. The IJC has not been invited to participate. Environmental impact statements have been prepared for both situations and the final resolution of the difficulties has not been reached.

The concerns of U.S. border states led to the passage of a resolution in the U.S. Senate that:

> "... the Secretary of State should make every effort to negotiate a co-operative agreement with the Government of Canada aimed at preserving our mutual airshed so as to protect and enhance air resources and insure the attainment and maintenance of air quality protection of public health and welfare."
> (Senate Resolution 465, 1978).

Although this resolution was motivated by the relatively localized transboundary-pollution issues, it is apparent that the LRTAP problem is of far greater significance and both Governments have recognized that an air treaty or agreement would have to address this as well.

Multinational Agreements

There are several major international environmental forums that both Canada and the United States participate in that are related to this issue. Both countries were signatories to the Stockholm Declaration on the Human Environment; Principle 21 of which states:

> "States have, in accordance with the Charter of the United Nations, and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction of control do not cause damage to the environment of other States or areas beyond the limits of national jurisdiction."

The Environment Committee of the Organization for Economic Co-operation and Development (OECD) has adopted principles related to transfrontier pollution control. These principles which include exchange of information on research and monitoring and prior notification and consultation, are not binding but have been accepted as guides. At the present time discussions are underway within the environmental committees of the Economic Commission for Europe (ECE) of the United Nations. Both Canada and the United States are involved in these discussions and the results will be at least generally applicable.

Other agreements that may be relevant to Canada/U.S. air pollution relations are the Law of the Sea, the Ocean Dumping Convention and actions by the United Nations Environmental Program (UNEP).

PRESENT SITUATION

At the present there are significant transboundary problems due to air pollution fluxes. Most information is related to sulphur compounds, which may be summarized as:

1) There are significant transboundary fluxes of air pollutants. LRTAP models indicate that the northward flux over eastern North America is about three times the southward flux. For local areas the net flux may be from north to south;
2) The net LRTAP flux is of similar magnitude to the pollutant emissions in eastern Canada:
3) The aquatic ecosystems of eastern Canada are now being damaged by acidic precipitation resulting from the LRTAP and the extend of the damage is likely to increase.

In 1977, Romeo LeBlanc, the Minister of the Environment in an address to an APCA meeting in Toronto, identified the LRTAP as a major concern and called for Canada/U.S. discussions. Later, in the course of these preliminary discussions, Canada proposed the establishment of a Canada/U.S. Research Consultation Group (RCG) on the LRTAP. This Group met July 26-27, 1978 in Research Triangle Park, North Carolina and March 6-7, 1979 in Downsview, Ontario. The Group has provided a useful form for the exchange of information and for developing co-ordination and co-operation between research programs. Further, as part of its first annual report (due July, 1979), the RCG will provide an overview and preliminary assessment of the LRTAP problem in eastern North America. It is expected that this and future reports will form a scientific basis for air treaty discussions between Canada and the U.S.

The first round of discussions on transboundary air pollution was held in Washington on December 15, 1978. Further discussions are to be held this spring and summer.

Any agreement on air pollution must deal with both the local problems and the LRTAP problems. For the latter, the

identification of specific sources and specific damage is usually not possible. Further, the air pollution concentrations are not the problem in that they usually do not exceed air quality objectives. It is the cumulative deposition of the pollutants that results in damage. Hence, the procedure by which air pollution should be controlled is not clear. Several options are available. One approach could be called the liability option under which costs of damages would be paid. This suffers from the problem of difficulty in relating specific damages to specific sources. A second option would be common emissions standards. This would be easiest to apply but neglects the accumulation of sources. A third option would be the establishment of acceptable ambient air quality objectives or standards. A related option would be to specify the limits on transboundary pollutant fluxes, i.e., the concentrations of air crossing the border.

Other possible options and combinations of them will be considered. Each has advantages and disadvantages and it is not possible to say which should be adopted at this time. It is expected that the air pollution discussions between Canada and the U.S. will evolve from a statement of acceptable principles to the specification of control methods. Canada must ensure that its environmental, political and economic interests are all protected simultaneously and this is not an easy task.

DISCUSSION/COMMENTS

R. LAWFORD: I was wondering, Gord, what attitudes and positions you see being taken by the Americans that will cause major stumbling blocks or obstacles in the formulation and acceptance of a treaty, and secondly, what role do you see for Regional Directors General in the formulation of the treaty?

G.A. McBEAN: Those are two very loaded questions. Are there any Regional Directors General here? Okay. At the moment our discussions with the Americans are encouraging, and there are not going to be significant road blocks. One might have to be concerned as it becomes more apparent that the flux, the problem of air pollution is primarily of U.S. origin coming into Canada, and that some estimates I've heard are the order of 5 - 10 billion dollars per year to implement even the first order kind of controls to the extent that some people think might be required, that the costs are rather immense. There may well be a more difficult problem in the six months to a

year down the road. At the moment things are looking rather good, and we're trying to take advantage of it. In the future I can foresee problems, and as Dr. Collin said earlier, one shouldn't be optimistic there is going to be a treaty next month, or even next year, that we are a few years away from an agreement, perhaps. I don't know the jargon, but the jargon is either agreement, treaties or conventions, and they seem to be somewhat different. The Regional Directors General are being involved in the Steering Committee of the Long-Range Transport of Air Pollution Program. They were invited to the last meeting, and I think two of them attended; M. Lortie and Mr. Edmunds from Atlantic. It is intended that the R.D.G.'s play the role of liaison with the provincial governments re the scientific program. Now their role in the actual air agreement discussions is not clear at the moment, but it is certainly intended. External Affairs plays the lead there, so they're not particularly concerned about our R.D.G.'s at the moment, but they are very aware of the fact that the provinces must play an important role in this discussion, and they intend to bring them in, I gather, soon. It is interesting though that Premier Davis has written to Prime Minister Trudeau insisting that the federal government negotiate an air treaty with the United States, and saying that this problem of U.S. pollution coming into Canada is beyond their control. So in the case of Ontario, anyway, there is the recognition that this is a problem that Canada and the U.S. will have to face and not a thing that Ontario can negotiate with the United States.

H.L. FERGUSON: I might add a comment on developments in Ottawa in regard to the Long-Range Transport Program. There has been a proposal made that a federal/provincial committee might be formed for the purpose of discussing the negotiations with the United States, and within our own department, I think it's certainly recognized that AES has a leading role to play on the scientific side of the LRTAP program, but EPS has been taking the lead in terms of negotiations on transboundary pollution with the United States, and that appears to be the way that senior management wants to play it within our department. It does look as though we would wind up with the two committee structure; the steering committee for the scientific LRTAP program (that's under AES Chairmanship), and probably a federal/provincial committee specifically on the control aspects of LRTAP, which likely would be under an EPS Chairmanship. The Regional Directors General who participate in the steering committee as Gord has said, would probably also be members of the federal/provincial committee, and would be expected then to play a leading role on behalf of the department in each region, and dealing with the provinces in that region, both scientifically and on the control aspects.

H.E. TURNER: Gord, I have some concern with respect to the potential air treaty, that a commonality of air quality standards might become part of that treaty, because this would be most important close to the border region, and you could infer from that there would have to be a commonality of land use planning in this area, and we are somewhat constrained in Canada to live a little closer to the border that the United States, and I think that puts us at a distinct disadvantage. Do you have any comments as to whether ambient air quality objectives are seriously being considered as part of this treaty?

G.A. McBEAN: Well, no decision has been made as to what kind of approach we should take, but it is certainly being considered as one of the options. At the same time though, we are very aware of the fact that we do want to have a system that allows Canada to decide in Canada how we will meet requirements

of an air agreement with the United States; One would try and establish an agreement such that we have national or internal flexibility as to how we ensure that we do not cause them a problem, and give them the same rights there. It's a difficult problem though. I hope all these things will be taken care of.

D.M. WHELPDALE: Gord, I'd be interested in your comments on the strategy that Canada is pursuing in these air treaty negotiations. At the public hearings that Ontario held a couple of months back there was a fair outcry in the press about the lack of action on the part of both the provincial and federal governments for going ahead with negotiations to actually do something about long-range transport and acid rain. So there is quite an urgency to negotiate something, but on the other hand, in Scandinavia, they've had substantial research programs in place now for 7 or 8 years and I think they're really working from a position of strength, as far as scientific base is concerned, yet they're having a great deal of difficulty making much progress in negotiations. If you look at the draft convention for the high level meeting coming up, it's a pretty watered down sort of effort, so there's this dichotomy of an urgency, but should we really be going ahead too fast when we have to build up our own base of information?

G.A. McBEAN: Yes, that's a problem. As a member of the scientific community, I have tried to stress at meetings that we should not go ahead faster than our scientific basis of information will allow us to justify our position. Because there are considerable economic considerations that come into this, I think there will be a reluctance or pressure from industrial groups not to do anything about this problem, so we must have our scientific basis well established. The Canadian strategy, at the moment, is to try and take advantage of the U.S. interest, the U.S. Senate resolution to try and get something going. Probably all that can be expected in the near future is some kind of agreement in principle, and agreement that we abide by Stockholm Principle 21, that the boundary waters treaty is an interesting document, and we'd include in our discussion the kind of things that we think are important without specifying the details of an air agreement, but specify them in such a way that it would force the parties to continue to negotiate toward an air agreement over a period of time. At the moment, the discussions are what External Affairs called informal. They are technically not meeting, although they are meeting. This leads to complications, I gather.

R.M. HOFF: Gord, to what extent can External negotiate an agreement with the States without full agreement of all the provinces? For example, if you do come up with guidelines, do you have to have full provincial agreement from all ten provinces that those guidelines will be enforced and does that in effect put a national air quality guideline for Canada by doing that?

G.A. McBEAN: That's a good question; I don't really know fully the answer, particularly in view of Ted (Turner's) presentation before me. One suspects that it probably could be negotiated if it refers specifically to transboundary problems, but of course as soon as it crosses this infinitesimally thin boundary, it's in a province, and I am not quite sure how you handle that problem. I don't know the answer to the question, really. The provinces have already been brought in to some extent at briefing sessions. This will be discussed at the Canadian Council of Resource and Environment Ministers meeting in June, and as Howard mentioned, there will be this federal/provincial coordinating or steering committee for the air treaty or air negotiation discussions, so that

will hopefully take care of those problems.

H.E. TURNER: I'd like to comment on Ray (Hoff)'s question, there are two questions there: the one is could Canada in fact negotiate a treaty without getting the agreement of the ten provinces. That one may be difficult to answer, could it? The more sensitive question is: would it? And my feeling is that we most certainly would not.

ENVIRONMENTAL IMPACT ASSESSMENTS IN CANADA: AES POLICIES AND PROCEDURES (EARP)

H.L. FERGUSON

AES Scientific Program Coordinator

INTRODUCTION

The purpose of this paper is to examine the AES role in the Federal Environmental Assessment and Review Process and related activities. Some current problems will be discussed and possible solutions suggested. A general approach will be taken but specific reference to air quality will be made in a few cases.

DESCRIPTION OF THE FEDERAL ENVIRONMENTAL ASSESSMENT AND REVIEW PROCESS

Figures 1 to 7 provide a description of the Federal Environmental Assessment and Review Process (EARP) and in particular the inputs of DOE and AES to the process.

An important point to note is the primary role played by the five DOE Regions. In particular, the responsibility for the DOE review of an Environmental Impact Statement (EIS) is normally assigned to a Region, with the Regional Director General (RDG) as the responsible manager. This is the case even when the development project affects more than one Region. For example, the Arctic Pilot Project (APP) proposes to gather natural gas by pipeline at a terminal in the western Arctic, liquefy it at that location and transport it by ice-breaking LNG tankers to a terminal in the Maritime Provinces. The Departmental Western and Northern Region has been assigned a lead responsibility with respect to this project. Clearly, the Departmental review of the EIS should include inputs from other Regions and particularly Atlantic Region. Figures 3 and 4 describe the process by which the various inputs of Services and Regions are obtained as inputs to the coordinated Departmental review of the EIS.

This method of operation follows the general Departmental policy on delegation of responsibility to the Regions and is

particularly suited to the decentralized organization of EMS and EPS. In the case of AES, which has the bulk of its applications and research expertise centralized in Downsview, it raises some unique problems of communication and coordination.

From the point of view of the Environmental Assessment Panel, the process might be deemed to end when the Panel has published its report. Generally speaking the Panel makes recommendations which require follow-up actions on the part of DOE, other government departments and industry. Figure 8 describes the procedure for determining Departmental follow-up actions.

Figure 9 outlines the procedure developed by Western and Northern Region for carrying out the Departmental review of an EIS in a particular case - the Arctic Pilot Project.

RELATED ACTIVITIES IN A DEVELOPMENT PROJECT

In many cases the Environmental Assessment and Review Process represents only one aspect of the longer-term relationships involving a private company and government departments. The Departmental and AES EARP-support systems must be integrated into the broader context of programs and development projects.

For most development projects a number of related activities can be identified. These include the ongoing baseline information activities of the Department and the Service, contingency planning and responses to environmental accidents, monitoring of projects to evaluate and improve impact predictions and control measures, provision of advice to licensing agencies on environmental terms and conditions, and the consideration of federal-provincial and international aspects of environmental impacts.

In many cases AES may be directly involved in the provision of environmental prediction services during the operational phase of projects, and/or responsible for ensuring that such services are adequate to ensure "best practicable" protection of the environment. Examples are the provision of weather and ice prediction services to support offshore drilling or the provision of operational air quality parameters in connection with stack

emission control procedures.

Figure 10 illustrates, for the case of offshore drilling, the relationships between the EAR Process, ongoing multi-agency functions, and AES support of project operations.

PROBLEMS WITH EARP AND RELATED ACTIVITIES

Table 1 synthesizes some of the current problems with EARP and related environmental quality activities, along with possible solutions. Progress is being made on some of the solutions.

The problem of realistic scheduling of EARP activities has been a serious one. Frequently there has been insufficient time for the Department to respond adequately to EIS's because insufficient time was allowed for review, considering the needs for many inputs from various parts of the Department. The situation has recently improved with the publication of the Senior Management Committee paper on DOE-FEARO relationships and the provision by the FEARO of monthly Panel Projects Status Reports (Figure 11) and information on Active Panels (Figure 12). The concentration on energy development projects is worthy of note. A number of these projects involve possible air quality impacts.

In general EARP-related activities in Downsview have been carried out without specific dedicated resource allocations. In contrast, the Headquarters components of EMS and EPS, respectively, include an Integration and Environmental Assessment Branch and an Environmental Assessment and Design Division.

In the absence of other arrangements, the Scientific Program Coordinator in Ottawa (APCO) has attempted to coordinate Downsview inputs to the reviews of EIS's, contingency plans, etc., but physical separation leads to delays and inefficiencies. Regional and Headquarters components of AES have agreed that improved coordination in Downsview would be desirable, and a Downsview EARP Office has been proposed.

Figure 13 summarizes most of the EARP-related activities of the APCO Office in Ottawa for the period January to April, 1979. If a Downsview EARP Office is established, APCO would still be involved in a wide range of activities but a significant

TABLE 1 - SOME PROBLEMS IN EARP AND RELATED ENVIRONMENTAL QUALITY ACTIVITIES

	PROBLEM	POSSIBLE SOLUTION
EARP - Federal Government	Based on Cabinet Decision - limited authority and application; inconsistencies among OGD's	Legislation; encourage consistency
EARP - DOE	Limited authority; OGD's with environmental mandates; complex communications	Legislation and/or increased horizontal powers; SMC Paper on DOE-FEARO Relationships; FEARO status reports and scheduling
EARP - AES : Regional Downsview Ottawa	Communications and coordination difficulties; Limited resources	Develop better systems approach; improve coordination; apply more resources; improve motivation
IMPACT PREDICTION	Lack of knowledge and perception especially on long term, cumulative, synergistic and infrastructure effects	Improve knowledge; increase awareness of public, OGD's; incorporate in environmental requirements; monitor effects
BASELINE INFORMATION	Deficiencies in practical use and interpretation of available data; deficiencies in planning new data acquisition priorities	Improve analytical models; put more emphasis on synthesis, interpolation, transposition, remote sensing; use economic planning scenarios
CONTINGENCIES : Planning Response	Inadequate attention to environmental prediction; inadequate public information response; deficiencies in Gov't planning	Improve models and use of models; apply standards; improve public information; improve guidelines for contingency plans
TERMS AND CONDITIONS	Environmental concerns not fully addressed	Improve communications with licensing agencies and improve their understanding of environmental requirements
PROPRIATARY INFORMATION	Private sector reluctant to make data, models, etc., available	Foster cooperation, develop cooperative cost-sharing; respect confidentiality where appropriate
CONFLICT OF INTEREST	AES service function and regulatory advice function perceived as conflict of interest	Improve credibility by persuasion, communication and performance. provide standards and guidelines for meeting environmental requirements
FEDERAL-PROVINCIAL RELATIONS	Overlapping mandates; varying provincial perceptions and interests; duplication of efforts	Develop cooperative approaches; recognize regional needs and disparities while promoting national interest
INTERNATIONAL RELATIONS	Deficiencies in knowledge base; socio-economic aspects of control strategies; policy conflicts; case-by-case adversary conflicts	Encourage international accords and cooperative scientific programs; polluter pays principle; develop mutual agreements on environmental requirements; improve Canada's scientific knowledge base and its application

portion of the current workload for each project would be transferred.

A continuing problem with the EAR Process is the evaluation of environmental impacts in the longer term. In particular, the AES must play a particularly strong role in identifying relationships between man's activities and climate (such as the CO_2 and fluorocarbon problems) and in protecting the environment through the continued development of best practicable environmental prediction systems.

It will be noted that Table 1 identifies a number of other problems and possible solutions of interest from an air quality point of view. For example, there is a need to continue our efforts to define acceptable environmental quality. This involves not only the specification of air quality objectives but improved understanding of environmental relationships such as the relationships between ambient air quality, deposition rates (wet and dry) and effects (such as lake acidification) on various time and space scales, including the longer-range effects.

Increased attention should also be focused on our ability to synthesize the current state of knowledge for practical purposes and to promote technology transfer so that existing information can be applied most effectively by AES staff, consultants in the private sector and government administrators. Workshops are useful in identifying needs of this kind and encouraging positive responses to those needs.

STAGE 1

Either an Industry (the Proponent) makes a proposal which involves authorization by the federal government, through one of its agencies (the Initiator), to proceed (because the proposal requires federal action such as funding or land granting), or a federal government agency (the Initiator) makes a proposal.

The Initiator/Proponent carries out an environmental screening to determine areas of potential impact on the environment from the project. After determining the feasible mitigating procedures that will be applied, the remaining areas of impact are assessed. If these are deemed negligible, then the project proceeds, incorporating the mitigating procedures. If the impact is significant, the project goes directly to Stage 2. If the areas of impact are not adequately known, then an initial environmental evaluation (I.E.E.) is undertaken. This is prepared by the Initiator/Proponent, drawing assistance, if desired, from other Government departments (OGDs) such as DOE; particularly a Regional office of DOE. A review of the I.E.E. is then carried out and a decision made as to whether the probable unmitigated environmental effects are sufficiently well known and of such a minor magnitude as to not warrant formal submission to Stage 2. If this is the case then the Initiator proceeds with the project, incorporating all mitigating procedures. If not, Stage 2 is entered. FEARO (policy), DOE and others (technical) may assist the Initiator, in an informal manner, in making this decision, if so requested.

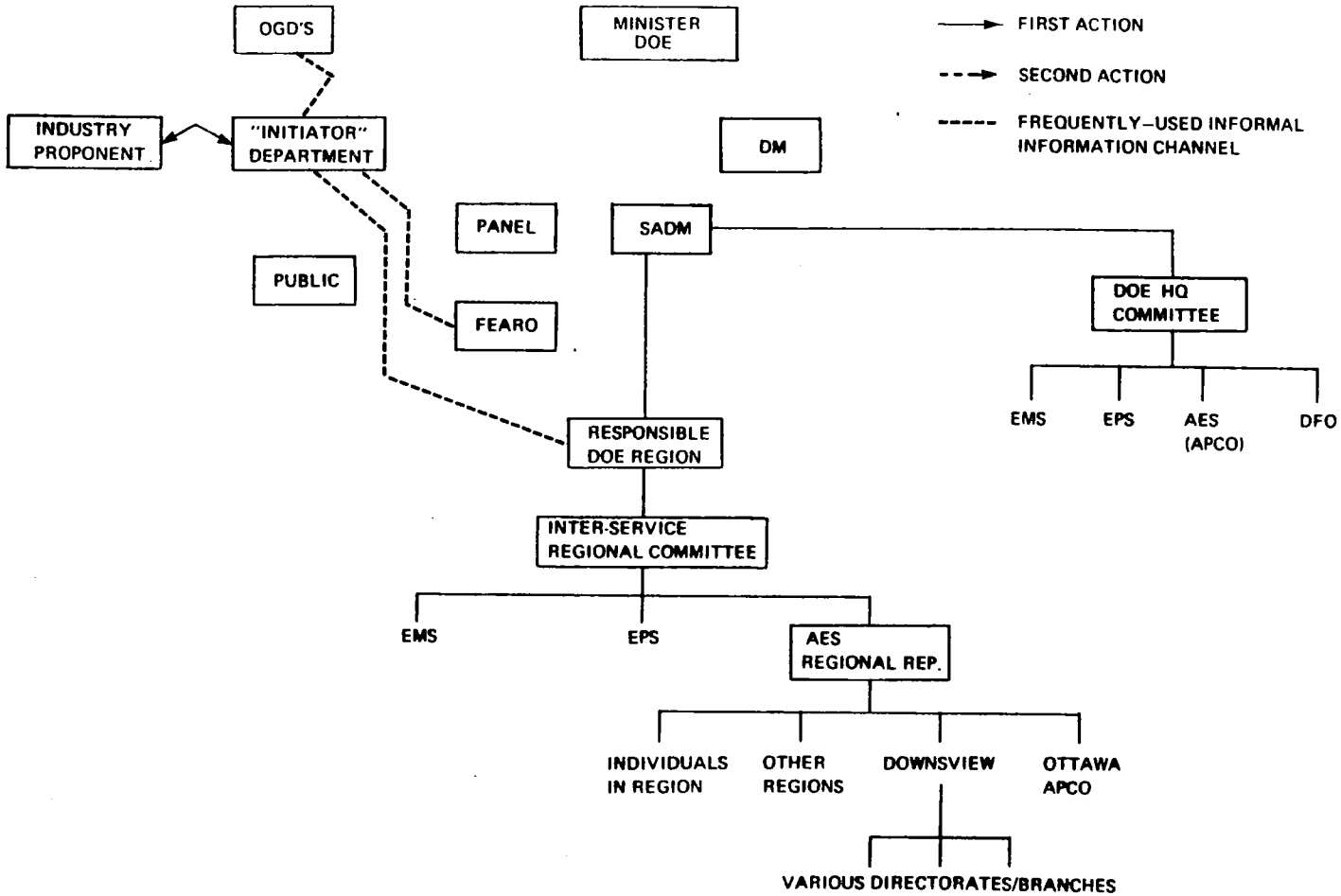

Figure 1

STAGE 2

The Initiator/Proponent, having decided that the proposal should be submitted for formal review, requests the Federal Environmental Assessment Review Office (FEARO) and the Minister of the Environment to establish an Environmental Assessment and Review Panel. (The Panel consists of a minimum of 4 experts drawn from any source and a chairman and secretariat from FEARO. The Head of FEARO can appoint any federal civil servant to the Panel while the Minister appoints those from outside).

The Panel issues Guidelines to the Initiator for the preparation of an Environmental Impact Statement. These Guidelines are passed to the Proponent.

The Environmental Impact Statement (EIS) is prepared by the Proponent in consultation with the Initiator, and, as appropriate, with DOE and other Government departments (OGD's).

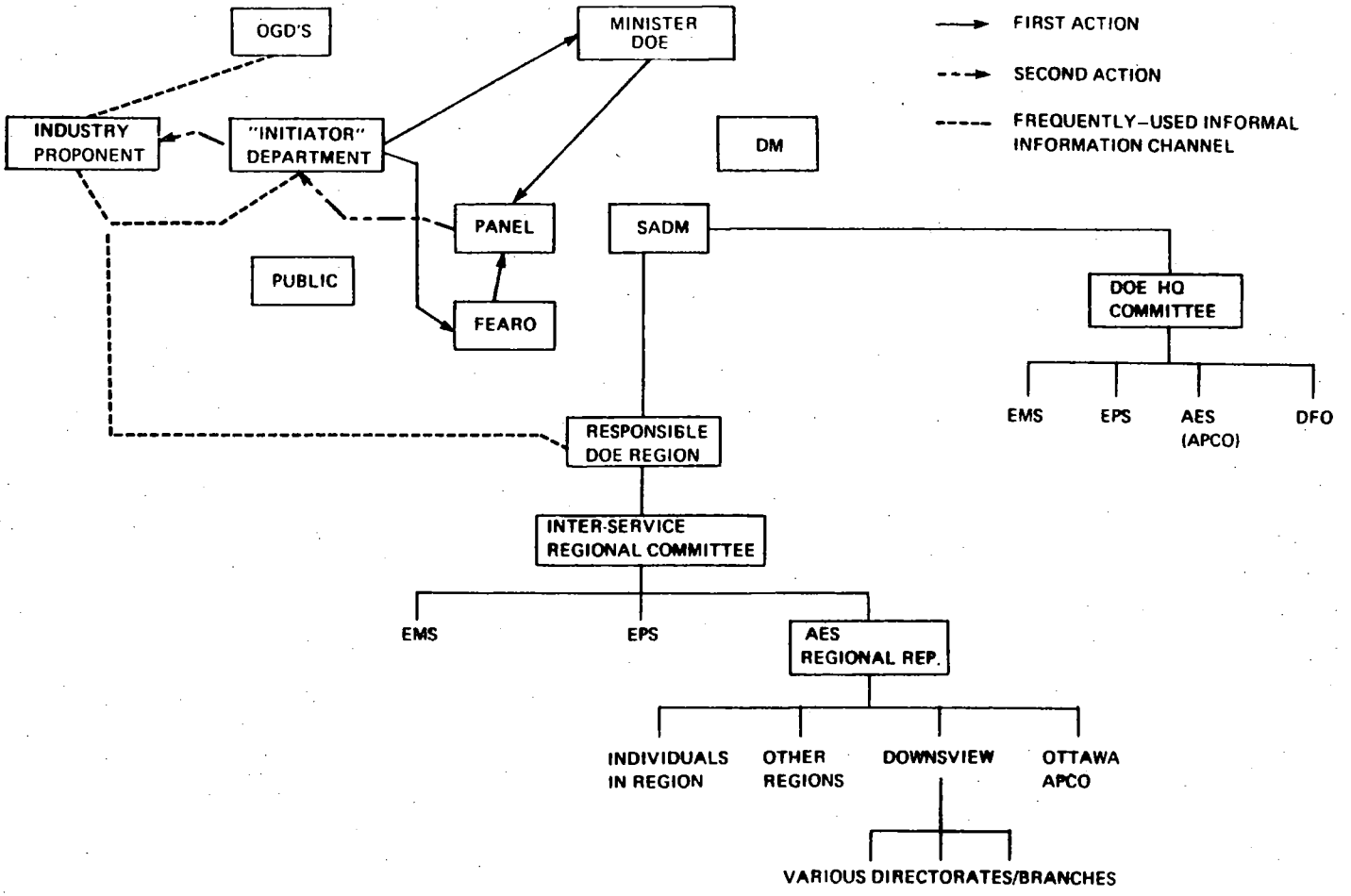

Figure 2

STAGE 3

The EIS is formally submitted to the Panel who then has copies distributed to DOE – SADM, OGDs, and the Public, requesting formal review comments, and establishes a time table for the stages of the Review process.

Responsibility for the DOE review of the EIS is normally assigned to a Departmental Region. (In unusual cases, responsibility may be assigned to a Service.)

Within the Region, responsibility for compiling the DOE response is assigned to an Inter-Service Committee.

The AES member requests comments on the EIS from appropriate AES staff in his own Region, in other AES Regions, in Downsview and in Ottawa.

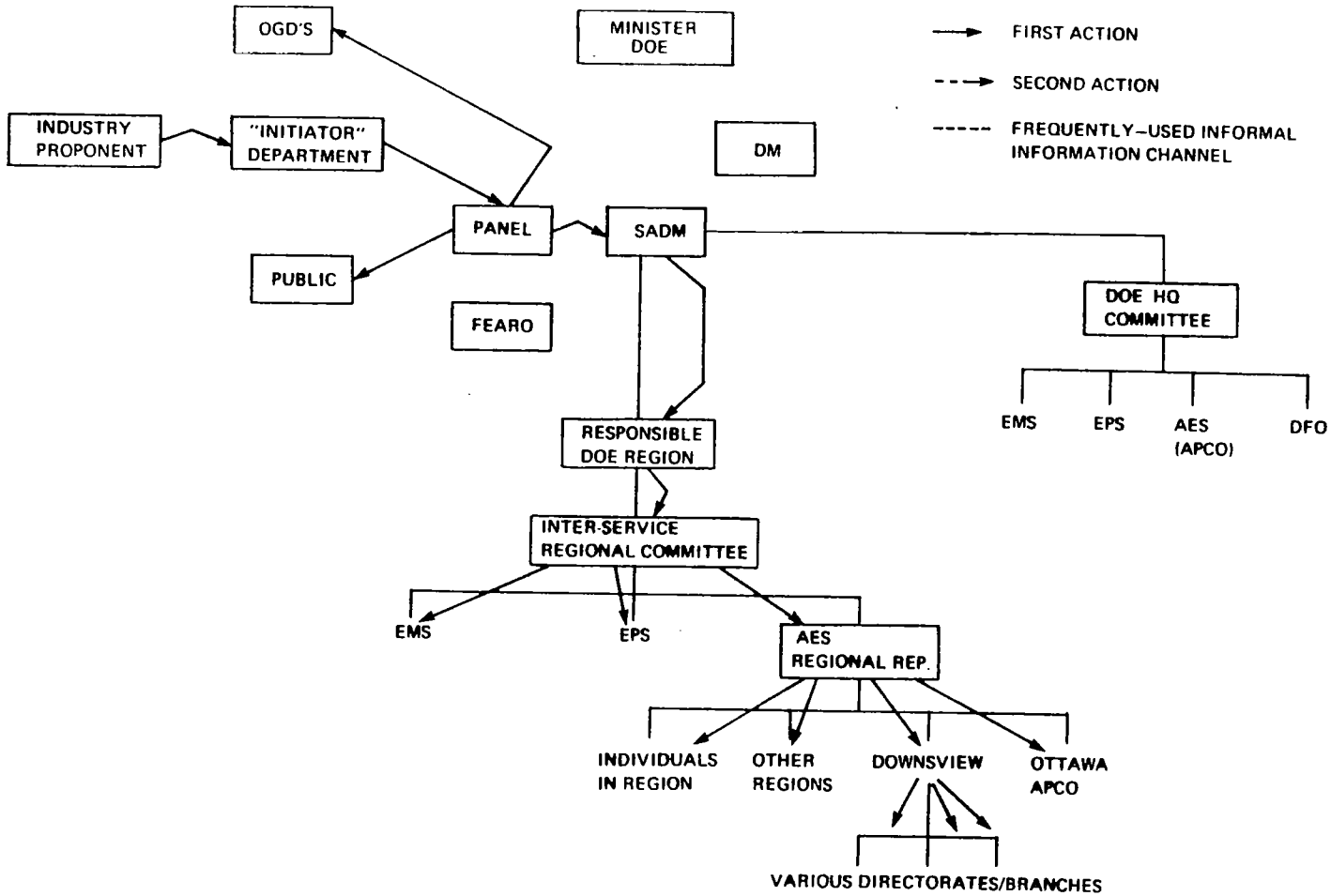

Figure 3

STAGE 4

The comments from individuals in AES are coordinated into an "AES position" by the AES Regional representative.

The comments from all Services are coordinated into a Departmental position by the Inter-Service Regional Committee, reviewed by senior regional management and transmitted to the SADM.

The Departmental position is reviewed by the SADM. He may consult with senior regional management and with service representatives at DOE Headquarters.

The DOE review is brought to Senior Management Committee's attention by the SADM and then submitted to the Panel.

The Panel releases all the reviews to the Public, the Initiator, OGDs, and the Proponent.

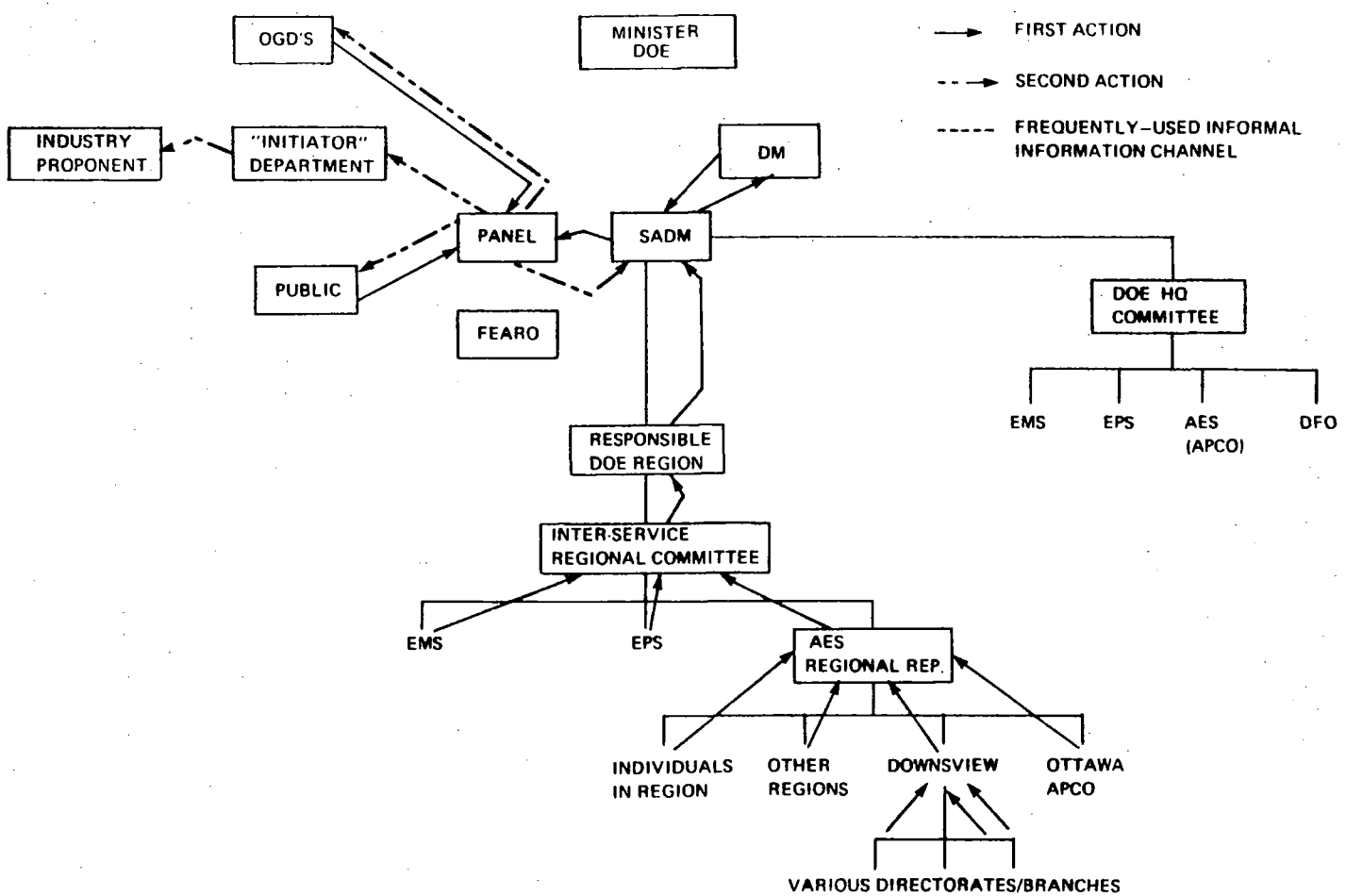

Figure 4

STAGE 5

The Panel holds informal public hearings. Submissions are heard from all interested parties including the Proponent, the Initiator, DOE, OGDs, environmental non-governmental organizations (ENGOs) and concerned citizens.

The Panel may call on expert witnesses as appropriate. Some of these may be DOE employees asked to provide expert personal opinions on specific issues. These DOE employees may be from any regional or headquarters component of DOE.

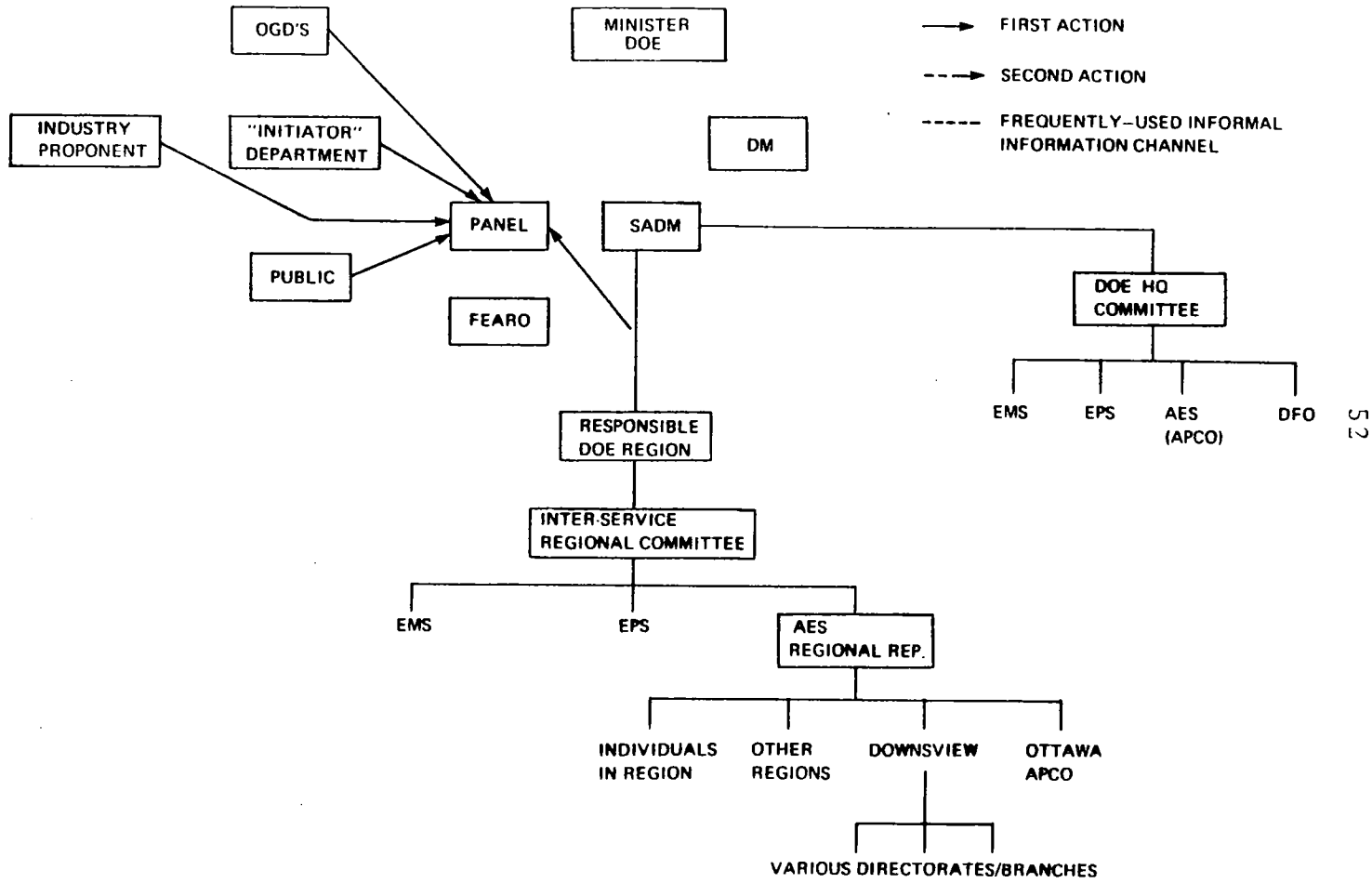

Figure 5

STAGE 6

The Panel passes its final printed report (decision) directly to the Minister of DOE only. He reviews the report and decides what action should be taken. He may, at his discretion, release the report and his comments on it to the Initiator's Minister, to the Public and all Government Departments simultaneously, or he may request advice from within his Department first before release.

The Minister may seek clarification from the Panel Chairman concerning the Panel Report. However, no changes will be made to the Panel Report.

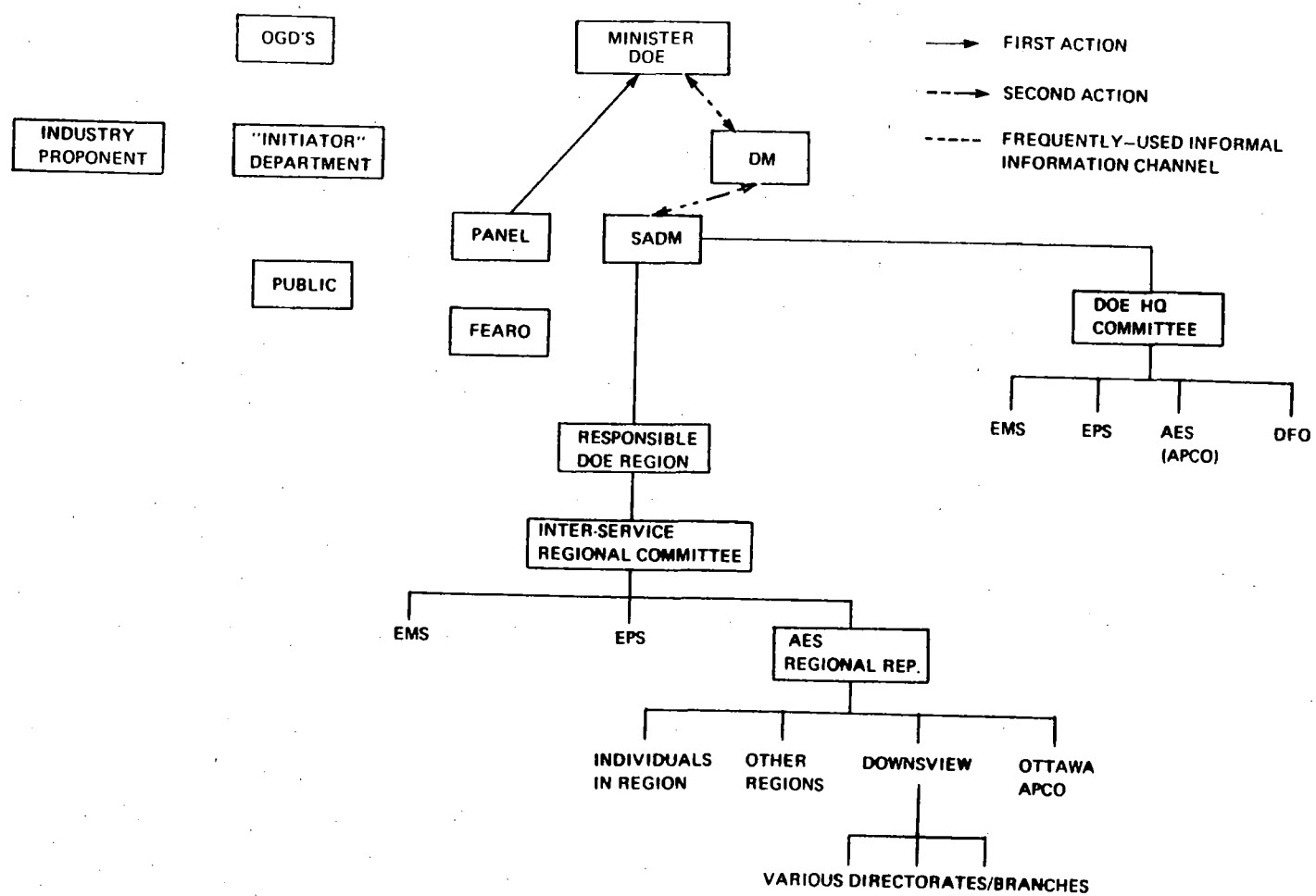

Figure 6

STAGE 7

The report and the DOE Minister's comments on it are released to the Initiator's Minister, the Public, and all Government Departments simultaneously.

If the Ministers, and particularly those of the Initiator and DOE, agree that the Panel Report is acceptable, the Initiator will advise the Proponent of the Government decision, i.e., that the proposal is rejected or that it can proceed (subject to terms and conditions to be specified).

If interdepartmental conflicts still exist, e.g., the Initiator-Minister decides to Go, though the DOE Minister says Stop, the question of whether the project will be approved by the federal government will be referred to Cabinet for a decision.

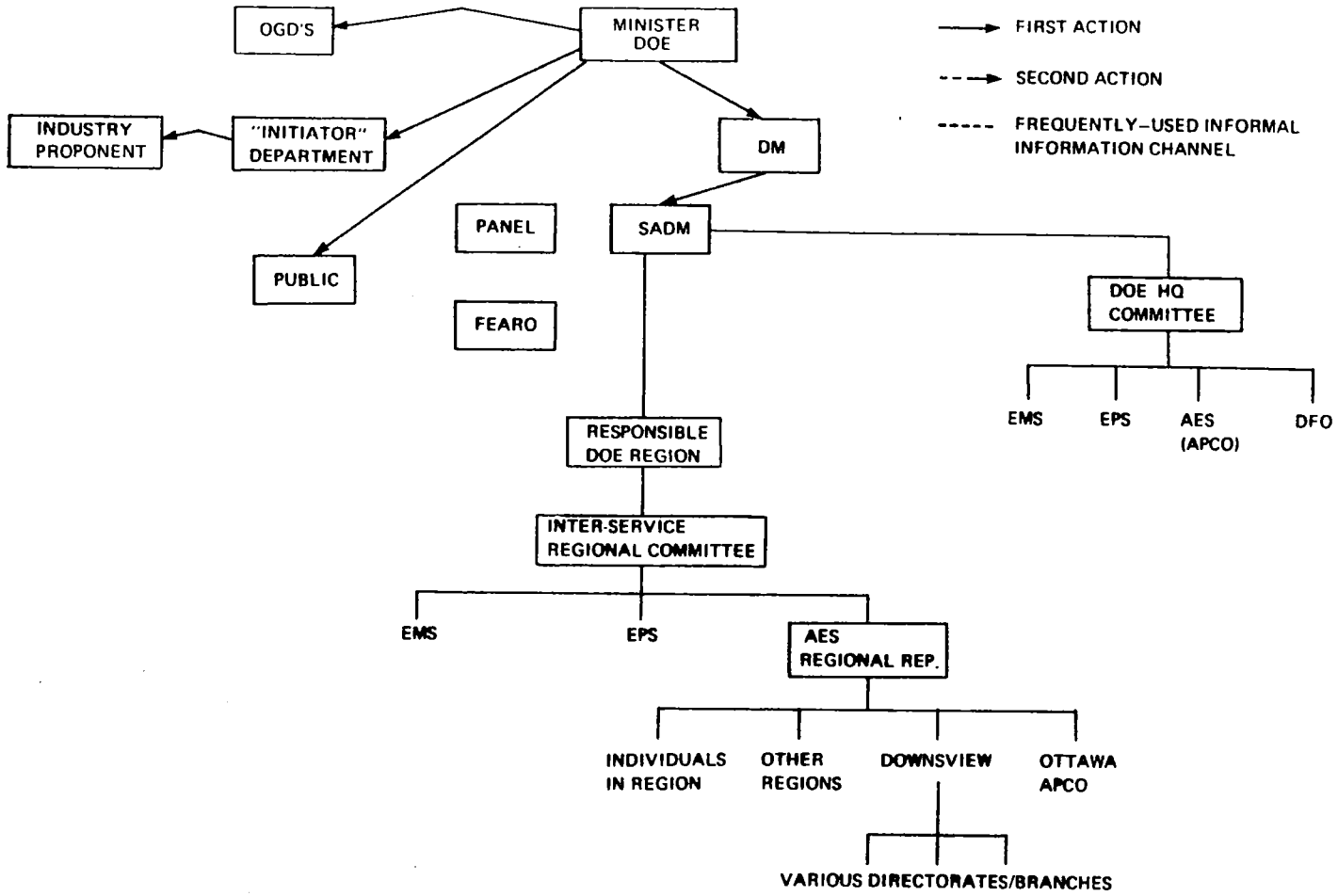

Figure 7

STAGE 8

The Panel Report is reviewed by the DOE Headquarters Committee. The SADM may also seek advice from other Departmental representatives, in particular from the Region responsible for the EIS review. The purpose of the Panel Report review is to identify appropriate DOE follow-up actions, possible political sensitivities and anticipated reactions from the proponent, initiator, etc., which might require a further response from the Minister.

The SADM provides advice to the DM and the Minister based on the review of the Panel Report.

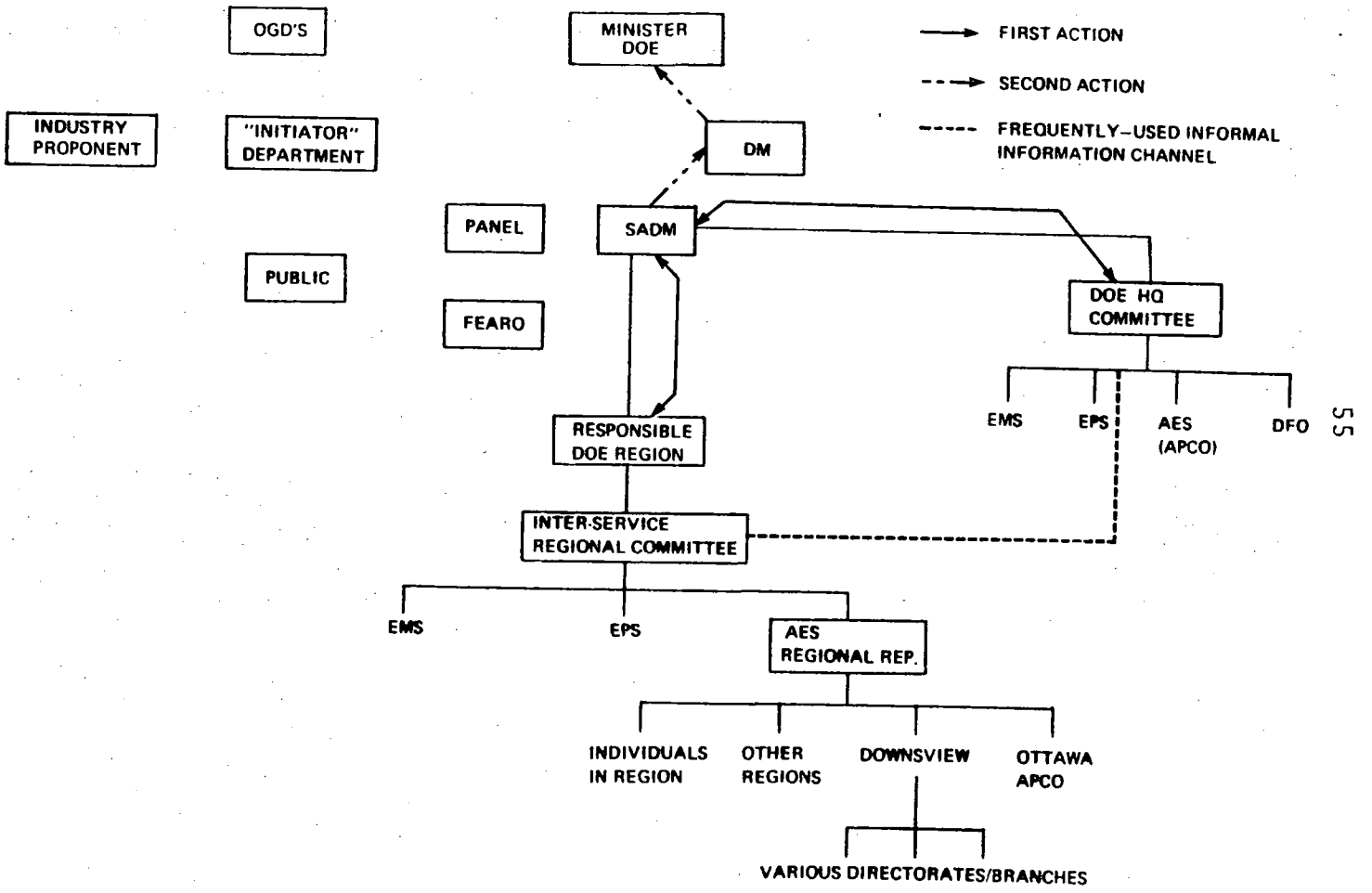

Figure 8

Figure 9

ARCTIC PILOT PROJECT
EIS REVIEW PROCESS

Prepared by M. J. Lawrence

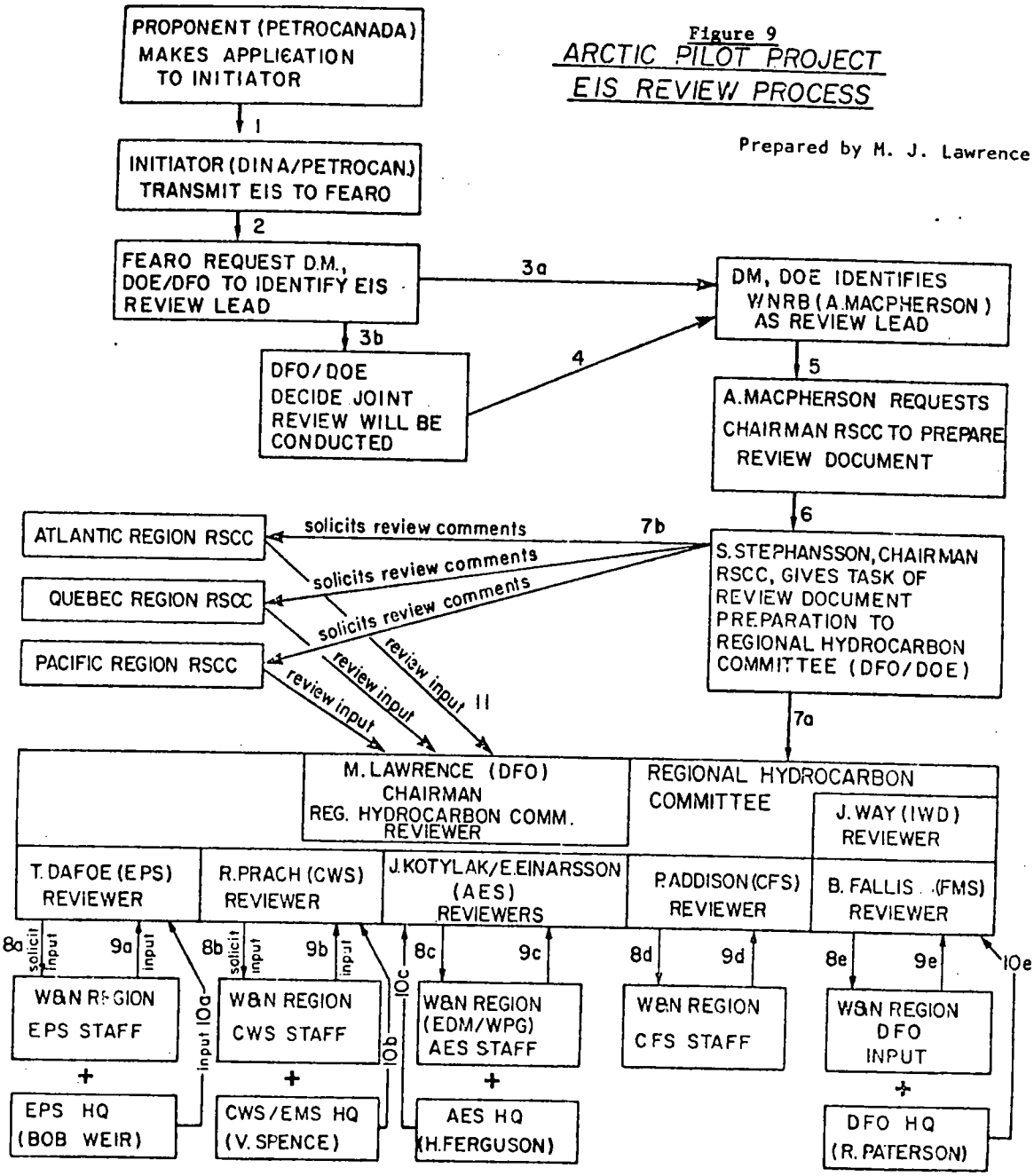

Figure 10. AES INTERFACE WITH INDUSTRY-OFFSHORE DRILLING

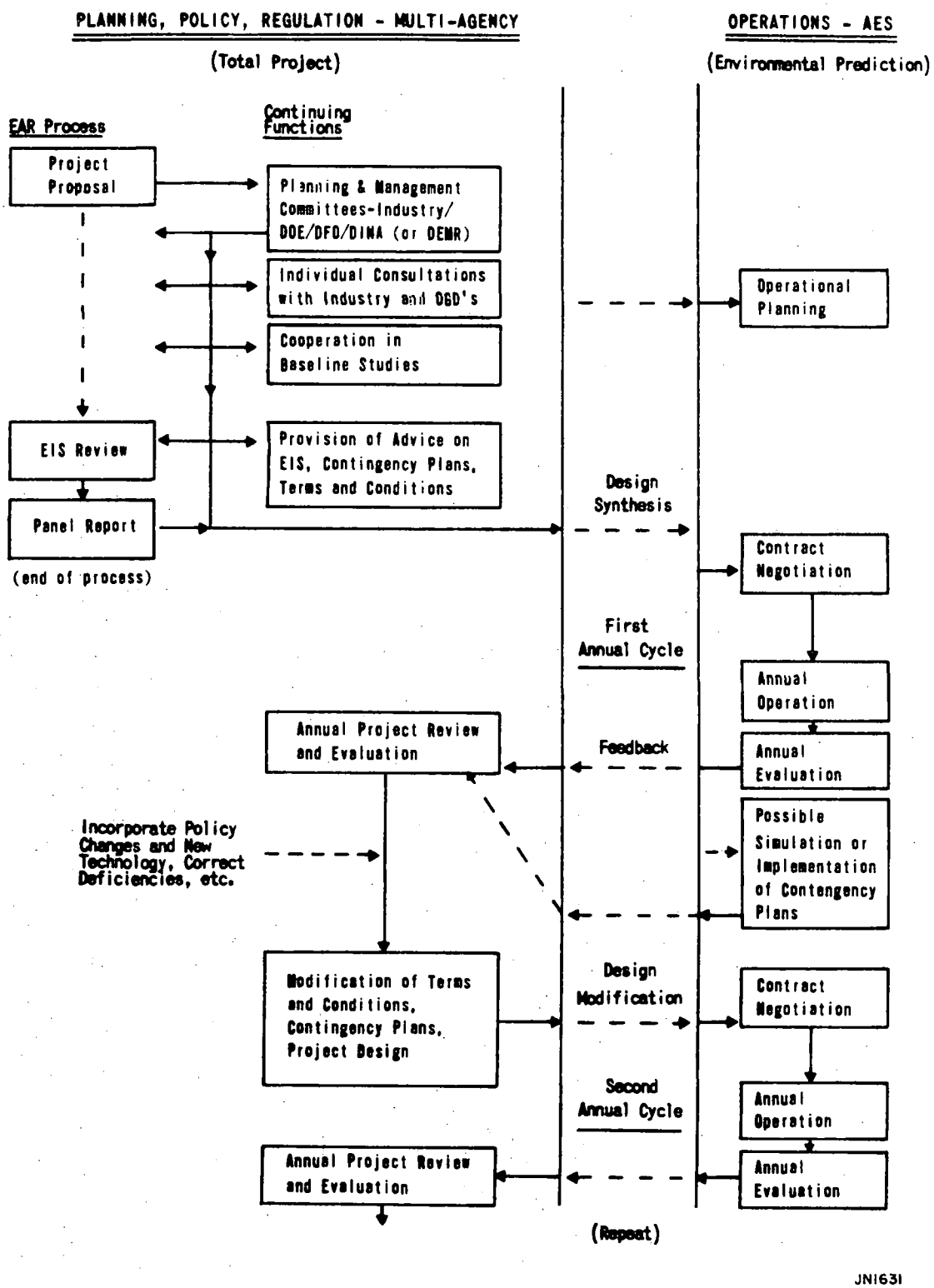

Figure 11 PANEL PROJECTS STATUS REPORT
RAPPORT SUR L'ÉTAT DES PROJETS SOUMIS À UNE COMMISSION

PROJECT TITLE (& LOCATION)
TITRE DU PROJET (ENDROIT) Arctic Pilot Project

INITIATING DEPARTMENT
MINISTÈRE RESPONSABLE
Petro-Canada (M. Homan) and
DINA (M. Ruel 819-997-9381)

PROPONENT Petro-Canada
PARRAIN M. Homan (403) 232-8432

FEARO CONTACT
CONTACT AU BFEEE R.G. Connelly (819-997-2725)

MOST RECENT EVENT(S) DERNIER(S) ÉVÉNEMENT(S)	DATE(S) DATE(S)
E.I.S. issued by Petro-Canada and sent out for government review	February 1979

FORECASTED EVENT(S) ÉVÉNEMENT(S) PRÉVU(S)	EXPECTED DATE(S) DATE(S) PROBABLE(S)
-Deadline for technical comments on project and EIS	May 1, 1979
-Panel decision on EIS adequacy/deficiencies	June 1, 1979
-Public review (depending on deficiencies)	June-Dec. 1979
-Public hearings (depending on deficiencies)	early 1980

OTHER COMMENTS
AUTRES REMARQUES

As co-initiator, DINA will advise Panel by May 1 on suitability of EIS from their point of view.

DATE PREPARED
DATE DU RAPPORT 79 04 06

CHANGE FROM PREVIOUS REPORT
NOUVEAUX ÉLÉMENTS [X] YES OUI [ ] NO NON

Figure 12. ENVIRONMENTAL ASSESSMENT AND REVIEW PROCESS:

LIST OF ACTIVE PANELS: APRIL, 1979

Alaska Highway Gas Pipeline Project
Arctic Pilot Project
Banff National Park Highway Project
Bay of Fundy Tidal Power Generation Project
Boundary Bay Aerodrome - Reactivation
Dempster Pipeline Project
Eastern Arctic Offshore Drilling - North Davis Strait Project
Eldorado Nuclear Limited - Expansion of Uranium Refinery Capacity (Saskatchewan)
Fraser River Training Works Program
Lower Churchill Hydro-Electric Environmental Assessment Project
Mackenzie Delta Gas Gathering System
Polar Gas Project
Quebec Port Expansion Project
Vancouver International Airport Expansion of Air Traffic Capacity
Yukon Transportation Study

Projects now in a state of suspension

C.N. Telecommunication System - Wood Buffalo National Park
Mackenzie River Dredging Program

Figure 13. SUMMARY OF EARP ACTIVITIES - APCO - January-April, 1979

Reviews of Environmental Impact Statements*

Alaska Highway Gas Pipeline

Arctic Pilot Project

Reviews of Panel Reports

Roberts Bank Coal Terminal

Southern Davis Strait Offshore Drilling

Lancaster Sound Offshore Drilling

Eldorado Nuclear Hexafluoride Refinery

Newfoundland Labrador Transmission Line

Reviews of Contingency Plans

Texaco	Esso Resources (Flemish Cap)
Total Eastcan	Esso Resources (Southern Davis Strait)
Chevron Hibernia	Aquitaine (Southern Davis Strait)
British Petroleum	

Committees

Doe Headquarters Pipeline Committee (Chaired by SADM)

Resource Management Environmental Committee (Chaired by DEMR)

Interdepartmental Environmental Review Committee (Chaired by DINA)

DOE Headquarters EARP Committee (Chaired by SADM)

Joint Government Industry Steering Committee (Chaired by APOA)

Other Consultations and Correspondence

Beaufort Sea and Southern Davis Strait Contracts, related terms and conditions, meteorological observing standards, ad hoc meetings to discuss company programs, etc.

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* Environmental Impact Statements typically run to hundreds of pages each, Panel Reports are typically 50 pages or more; Contingency Plans are usually in excess of 150 pages.

DISCUSSION/COMMENTS

G. DESAUTELS: On the diagram you showed earlier there was a mention of a DFO participation on the national headquarters committee, but there was no reference of DFO representation on a regional basis. Do you care to comment on that?

H. L. FERGUSON: Yes, my understanding is that in most of the regional screening and coordinating committees that DFO is still participating, they still have a member who sits in (on the meetings). I think we are trying to encourage as much as possible that cooperative approach and their participation in regional screening and coordinating committees as well as at the headquarters level. They are, of course, as a new department, quite conscious that they have a responsibility and a right to respond to Environmental Impact Statements independently of the DOE position but that can be allowed for in the cooperative arrangements that are set up. So I'm rather encouraged as to what has been happening so far but I'd like to hear your comments on that too. What does it look like from the regions' point of view?

H. FRASER: On the same subject, Howard, one of the comments I wanted to make was on the departmental split because it's obviously going to require some adjustments in the mechanisms. In Central or Western Region, AES, which is Western and Northern Region of DOE, we intend to maintain almost the status quo with our environmental review groups. I think the single exception that has been decided upon is so far that the DFO will not provide the chairman of the RSCC, but can provide the chairmanship of the review committees or task forces which report to the RSCC. I think this adjustment will be a rather delicate thing because even when we were all in the same department it was not unheard of for the Fisheries people to disagree with some of the others, particularly EPS, so we may be looking for a few more of those and I think that we can handle that alright. I suppose, Howard, that we can talk all day about EARP but I'll try to make some quick comments.

With regard to the recent mechanisms to review panel reports, which was an addition really to the original EIA process, my own opinion is that we will have to rely heavily on the headquarters committee of which you are a member to do that because I just can't see that the complex communication channels to get back down to the regional reviewers and back up again can really handle the situation in the time frame that the Minister needs. I know in our own region we have established the same channels, down then up again, and I honestly don't think that it's really going to work, because when you speak in terms of that sort of communication you are really speaking in terms of months and the Minister has to know within days.

One other thing was, I suppose this could have come up under Federal/Provincial Relations, but many of the things that we get involved in are non-EARP and in some cases it seems to be almost an extension of EARP to non-EARP processes, if you know what I mean. The province needs help and they call on DOE for that help. Sometimes they ask us directly for it and sometimes they ask another agency, principally EPS. If they ask EPS, the help is usually a little easier for us because we don't have to decide whether the help is within our mandate or not. If EPS asks us for help, they get it. If the province does, we have to decide on whether they get it. We also have to decide, quite frankly, whether headquarters is liable to supply it and I'm sure that that is maybe more of a problem in other regions than it is in ours. This problem of when you're in EARP and when you are not is a rather interesting one. The

RSCC does discuss things which are not federal jurisdiction or involved in the EARP. But north of sixty (degrees) it's almost always EARP, of course, because the government north of sixty is essentially the federal government. Anything that goes on up there falls very easily into this process but south of sixty in the provinces it is not. For example, in the recent proposals by Imperial Oil to extract oil in the Cold Lake Area it did not show up as an EARP project at first but it has now, mainly because DINA decided that there might be some air pollution or water pollution moved into Indian reservations. But that came after the review was underway and the review was an ad-hoc review by EPS (in a large part) with very little input by anybody else. Now it's all being rearranged and I think we're going to see it in an EARP where it probably should have been in the first place.

I could make many other comments but I won't except to say that in this EARP, I cannot see the Regions acquiring the expertise to handle it without a lot of headquarters backup for a long time to come; if ever.

H. FERGUSON: Yes, I think I would have to agree with that Hugh, from the pragmatic point of resources and how soon we're likely to have the detailed expertise capability in the region for dealing with the wide range of environmental problems and that may be a long time coming. So I think that it's encumbant on us to make the best possible use we can of the available resources in Downsview to apply to the process.

Along those lines, I do have some fresh news. I slipped out for about an hour this morning to attend the Management Committee meeting at which the EARP process was discussed and it was agreed that there will be an EARP office set up in Downsview to assist with the coordination function and there will be some resource allocation to that. The decision was, although I had made recommendations otherwise, that that component would be attached to the APCO office in Ottawa in terms of administration, but would be physically located here. So I'm hoping that that will make a contribution towards better communication and coordination within the Environmental Assessment activity.

AIR QUALITY ACTIVITIES - PACIFIC REGION

S. NIKLEVA
Scientific Services Division, Pacific

INTRODUCTION

Pacific Region involvement in air quality is related to: (a) the environmental assessment and review process, (b) EPS referral system and (c) consultation to industry, local government, consultants, etc. This paper reviews some of the major activities of the past year with respect to the air quality support provided by AES Headquarters.

ALASKA HIGHWAY GAS PIPELINE PROJECT

Description

A proposal by Foothills Pipeline Ltd. to construct and operate a 48-inch diameter buried gas transmission line to transport Alaska gas to U.S. markets. The project under consideration is the Yukon section of the line extending along the existing Alaska Highway for 512 miles. Estimated cost of this portion of the line is $1.24 billion.

AES Concerns

a) ice fog from compressor station operations, and

b) meteorological information required for hydrological considerations.

Field Studies

Deficiencies in available baseline data were identified in preliminary project proposals and a field study program was initiated to obtain sufficient data for a review of the EIS. Two joint field studies were carried out in November/December 1977 and 1978 jointly be Pacific Region SSD (minisonde) and ARQD (tethersonde, acoustic sounder, bivane anemometer). An additional minisonde study was undertaken by SSD in February/March 1978. All minisonde and tethersonde data were processed and published and a synoptic analysis of the minisonde data from the February/

March study was prepared. Non-salary costs associated with the field studies were funded from a special D.M. fund and by Foothills Pipelines Ltd.

ENVIRONMENTAL IMPACT STATEMENT:

When the EIS was received from Foothills for agency review the section on ice fog referenced a study in preparation by Slaney Consultants. PAES obtained a copy of the Slaney report (draft - subject to revision) in mid February. The required 60-day period for EIS review was therefore reduced to three weeks in order to meet the DOE Regional Task Force date requirement for agency reports. Comments on the EIS were received from AES Headquarters (CCAI, CCAH, ARQL) within deadline dates and further information on the Slaney study was provided by Saulesleja and Schemenauer.

In considering the frequency of ice fog the consultant had applied a model developed by Csanady and Wigley (1973) for the MacKenzie Valley Pipeline Project. The size of the ice fog particles in the compressor plume was a significant factor in the analysis of the frequency of ice fog at ground level. Advice on this matter was provided by Saulesleja and Schemenauer.

The AES submission to the Panel Hearings was prepared by PAES and sent to AES Headquarters for final comment. The brief concluded that ice fog would be much more prevalent than indicated in the EIS and recommended that before compressor station locations were finalized, each site be studied individually to ascertain ice fog impacts and to ensure that the impacts were acceptable. PAES presented the brief on ice fog at the EARP Panel Public Hearings held in Whitehorse April 23-27, 1978. The brief generated about three-quarters of an hour questioning. Foothills stated they were in agreement with the recommendations.

COMMENTS

Planning of the field studies was done in the first instance directly between PAES and ARQT (Turner) with other part-

icipants (Mickle, etc.) drawn in as study plans developed. The planning was therefore quite informal.

The data generated by the study has been of value. The consultant made use of the data in preparing the EIS and the data also provided the basis for AES disagreement with the consultant's report. The data have been published and are available for future dispersion modelling studies under Arctic inversion conditions. The field study program was therefore considered an unqualified success.

It would also appear that the review of the EIS with respect to ice fog was generally satisfactory. Foothills position as stated in the EIS was to dismiss ice fog concerns concluding that ice fog would occur so infrequently that it need not be considered. However, following presentation of the AES brief, Foothills agreed that the impact of ice fog should be studied at each compressor site.

An omission in the review was failure to comment on climatological change and its potential impact on the pipeline through the effects of temperature change on permafrost.

In summary, we feel that AES input to the EARP process was entirely satisfactory in this case and that both AES Headquarters and Regional components provided significant contributions. Notwithstanding the above statement, I must add that during most of the project there was a feeling of uneasiness as to who was actually responsible for the final scientific and technical positions adopted in our submission.

ROBERTS BANK PORT EXPANSION

Description

Proposed expansion of the existing Roberts Bank bulk loading facility into the offshore estuary area. The expansion would involve four new ship loading bays capable of handling coal and other bulk commodities. The proposed facility would cost $24 million.

AES Concerns

Airborne pollution resulting from storage and handling of non-containerized material and the gaseous emissions from ocean freighters.

EIS Review

Following receipt of the EIS a dificiency statement was prepared by Pacific Region SSD. This dealt mainly with deficiencies in use and interpretation of the meteorological data.

The DOE Regional Task Force was then instructed to prepare a Departmental brief for presentation at the Public Hearings. It was our understanding that EPS would be lead agency in preparing the air quality brief. The EIS, our deficiency statement and other supporting documentation were therefore forwarded to AES Headquarters for review in order that we would be in a position to provide comments on the EPS brief. The reply from ARQD was received within the three week time constraint. In further discussion with EPS it became apparent however that a brief on the air quality concerns was not being prepared. SSD therefore prepared the brief. It was reviewed by EPS and their comments were incorporated. The brief was presented by Schaefer, SSD at the Public Hearings.

Comments

The comments received from ARQD were very useful. They indicated some of the deficiencies in the EIS and suggested, in general terms, studies that would provide additional required information. However, to prepare the air quality brief required a further in-depth analysis. It was necessary to obtain additional information from the consultant to assess the accuracy of the predictions. In fact, the complete calculations had to be duplicated in order to appreciate how the data were manipulated.

The study incorporated measurements from two high-vol samplers with a Turner's workbook approach to derive emission rates. These calculated emission rates were then used in the model with climatological parameters to estimate projected particulate levels. To properly evaluate the procedure required a

detailed examination of the data base.

In summary, we feel the air quality concerns were adequately addressed in the EIS review. Although assistance was received from ARQD, considerable further work had to be undertaken in the Region before the specific weaknesses in the EIS could be determined and an appropriate response prepared.

HAT CREEK PROJECT

Description

The proposal is the development of coal deposits in Hat Creek Valley as a potential source of thermal energy of the generation of electric power. The proposed capacity of the first generating station is 2000 Mw with a further expansion to 5000 Mw.

AES Concerns

Consultants preliminary report suggested that untreated emissions (400 tons/day of SO_2 and 160 tons/day of NO_2) from tall stacks could be acceptable. The deposition of acid rain long distances downwind was therefore a major concern because of the significance of the fisheries resource in the Shuswap system and the potential adverse effect of small pH changes in those waters. Emissions of trace elements (fluorides, mercury, arsenic) are also of concern.

Developments

B.C. Hydro has undertaken numerous meteorological studies including data acquisition, gas tracer studies and dispersion modelling. SSD provided climatological data and consultation as requested. A meeting was held April 18, 1978 between EPS, PCB and AES headquarters and regional staff. AES headquarters agreed to provide the methodology for a simple atmospheric model to determine the "worst case" for acid rain potential. A suggested methodology for "estimating the lower bound on snow pack pH" was received from ARQD on May 15, 1978. In addition, copies of research papers on dispersion modelling that could perhaps be

applied to the Hat Creek study were received. The Air Quality Impact Studies prepared for B.C. Hydro by ERT Consultants are now being released, however, their consultant's report on long range transport and acid precipitation is not yet finalized.

Comments

In the preliminary stages of the study design B.C. Hydro requested assistance from AES in dispersion modelling but they received little encouragement and only limited response. If the Hat Creek Project goes ahead, the studies undertaken to date will probably form the basis of the EIS.

Further AES involvement will evolve from the review of the consultant's reports now being released, and from the priority given to the future development of the project.

AFTON MINE, MILLING AND SMELTING OPERATIONS - KAMLOOPS

Summary

In response to environmental concerns expressed at the Pollution Control Board Public Hearings, the air pollution permits for the Afton facility included the establishment of a Surveillance Committee. The Committee's terms of reference were to recommend to the Director, PCB a safe level for mercury emissions. Dispersion modelling of the mercury in the plume is a necessary step in determining the impacts. ARQD have provided limited assistance in arriving at a solution to this problem.

FUTURE OUTLOOK

(a) If there is a decision to proceed with the Hat Creek proposal, the AES will be involved in a major review of the EIS. Air emissions will be an extremely sensitive issue considering the potential impact to the substantial fishery resource.

(b) The Afton smelter flue gas monitoring program has not yet produced adequate data to estimate mercury emissions. However, as these data become available there will be additional pressures on AES to provide

information on the dispersal of this element.

(c) There appears to be an increase in the use of meteorological supplementary control systems in the province. Special forecast services to provide the necessary meteorological parameters may be requested.

(d) It is our experience that review of environmental impact statements are probably best done in the Regions with support from AES Headquarters. This requires an upgrading of air quality expertise in the regional SSD's so that the proper level of support can be provided from the regional office. Procedures to facilitate this training should be established.

AIR QUALITY ACTIVITIES - WESTERN REGION

J.T. KOTYLAK
Scientific Services Division, Western

A. INTRODUCTION

A.1. In the Spring of 1971 when our Service was transferred from the Ministry of Transport to the Department of the Environment, our Service was given additional responsibilities in the field of air pollution. Almost all of this responsibility was concentrated at Headquarters in the Air Quality Research Branch. Since then research activities have been directed at the development of an air pollution climatology for Canada, experimental plume-rise studies, urban and regional multi-source dispersion, wind-tunnel modelling, effects of pollution on climate, studies of urban meteorology, atmospheric chemical transformation, precipitation chemistry and acid rains, and on pollutant uptake rates by vegetation, lakes and other surfaces.

A.2. The Air Quality and Inter-Environmental Research Branch has, on occasion, promoted participation with AES Regional Headquarters offices in the conduct of special short-term site-specific air pollution investigations. In general regional involvement in air pollution activities, such as the provision of consultative services and expert advice and the participation in air pollution studies has been somewhat less than dynamic. In past times our directives and thrusts in air pollution meteorology at the regional level were not clearly delineated and hence not dynamically pursued. This has been, at least in part, due to our Service having no direct responsibility for air pollution control and hence no first line accountability for air pollution problems and secondly, because of the lack of a solid regional resource base in air pollution meteorology.

A.3. Events in environmental matters have changed significantly since the creation of the Department of the Environment, and indeed, since the creation of Scientific Services in the Regions. The present high-profile environmental concerns related to proposed massive industrial and energy producing projects is placing increasing demands on the AES to provide authoritative advice on the state and responsiveness of the atmosphere to these environmentally significant projects.

A.4. In the Western Region, recent air pollution concerns can be described within three general areas. One relates to the activities of the Provincial agencies having the mandate in air quality and our Service's relationship to the Provincial role. The second area of activity is the Alberta Oil Sands Environmental Research Program (AOSERP), a unique, unprecedented scientific environmental research venture. The third area relates to the increased emphasis on the assessment on the environment of the effects of large scale projects such as hydrocarbon and uranium exploitation.

B. The following three sections describe these three areas.

C. AIR QUALITY ACTIVITIES UNDER PROVINCIAL JURISDICTION

C.1. The Alberta Department of the Environment became a legal entity in early 1971, and was the first Department of the Environment in Canada, Provincial or Federal. The basic objectives of the Department were documented as working to conserve and improve the environment and on prevention of degradation or pollution. The Provincial Department has responsibility for monitoring and enforcing the Alberta Clean Air Act, Clean Water Act, Agricultural Chemicals Act, Litter Act, and the Beverage Container Act. As a consequence of a strong Provincial mandate on environmental matters, the AES Western Region has had little opportunity to become involved in Provincial environmental concerns except in an occasional

consultative role. Communication channels have been established with the Air Quality Control Branch of Environment Alberta and these lines are kept open.

C.2. In a cooperative effort, two towers in Edmonton and one in Calgary were instrumented to measure temperature and wind. Last year the Province took over the vertical profiling program completely. The Province also operates an acoustic radar to determine the thermal structure and heights of inversions and mixing layers in the atmosphere. The Province also maintains an extensive air quality monitoring network and has an intensive program for sampling effluents from stationary sources. Some of the kinds of studies which the Alberta Department of Environment have recently engaged in include:

- an analysis of the risk of pipeline failure near sour gas wells
- work with the Energy Resources Conservation Board in establishing guidelines for safe distances between sour gas facilities and other developments
- Alberta Research Council was contracted to evaluate the correlation spectrometer as a detector of nitrogen dioxide.

D. ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM (AOSERP)

D.1. The Alberta-Canada research program covering seven million acres including the Athabasca Oil Sands was undertaken to provide comprehensive scientific understanding of environmental matters in the oil sands area. Although AES has withdrawn from the program on April 1, 1979 because of Federal government spending cuts announced last September, there has been a significant contribution to understanding the environmental effects of large scale oil sands extraction projects upon the environment as a result of studies conducted to date. Western Region Scientific Services was

responsible for the meteorological data acquisition system in the Athabasca Oil Sands Region and provided support to the air quality research activities.

D.2. The data acquisition network was designed to establish baseline climatological data and together with the air quality network was to provide for a better understanding of atmospheric pollution processes relevant to the oil sands area. This can lead to the development of simulation models for the prediction of air quality and air pollution transport and deposition within and outside the oil sands area.

D.3. Some of the studies which were conducted and would best be described by the researchers themselves include:

- intensive field study to examine in detail the atmospheric characteristics of the Athabasca oil sands area under winter conditions, particularly as they relate to plume behaviour and dispersion;
- the feasibility of weather radar near Fort McMurray and in particular, the interactions between atmospheric pollutants and precipitation events;
- very high resolution meteorological satellite study of the oil sands weather to monitor paths of effluent plumes, occurrence of fog, etc.;
- data acquisition quality control network for monitoring chemical constituents in the air (Alberta Environment);
- inventory of sources and emissions in the AOSERP study area (Alberta Environment);
- plume dispersion measurements from oil sands extraction plant (Alberta Environment);
- preliminary investigation into the magnitude of fog occurrence and associated problems;
- a climatology of non-level air trajectories;

- a review of pollutant transformation processes;
- pollutant transformation processes consisting of a series of field measurements to determine sulphur dioxide oxidation rates in the GCOS plume in winter;
- plume rise and diffusion studies aimed at estimating the atmospheric dispersion coefficients relevant to pollution plumes from the GCOS plant by means of bivane turbulence measurements at the top of a 150 meter tower;
- literature survey on synthesis of turbulence measurements;
- application of the climatological dispersion model;
- atmospheric dispersion and transport model development.

E. ENVIRONMENTAL ASSESSMENT OF PROPOSED PROJECTS

E.1. The Environmental Assessment and Review Process (EARP), established by a Cabinet decision, encourages that projects in which Federal funding or Federal lands are involved be evaluated in terms of their environmental impacts. This requirement has placed increasing demands on Scientific Services in Western Region and on both AES and the Department as a whole. Some of the recent environmental impact statements (EIS's) in which Scientific Services, Western Region has been a reviewer included:

- Alaska Highway Gas Pipeline Project;
- Arctic Pilot Project;
- Banff National Park Highway Project;
- Eastern Arctic Offshore Drilling, South Davis Strait;
- Lancaster Sound Drilling Project.

Since many of the projects are in Canada's North, the lead responsibility for preparing the Departmental review is normally assigned to the Western and Northern Regional

Director-General of DOE and that directly involves Western and Central Regions of AES. In addition to the review of EIS's resulting from the EARP process, Western (and Central) Region have reviewed projects under Provincial jurisdiction. For example, the environmental impact statement for a uranium mining and milling proposal at Key Lake, Saskatchewan, was reviewed by Scientific Services, Western and Central Regions. We are also in the process of reviewing the environmental impact assessment reports for the Alsands Oil Sands development project and the Esso Resources Cold Lake Heavy Oil Plant project.

E.2. There is a need for an EARP or similar office in Downsview so that a timely and systematic approach to review of EIS's can be insured. Western Region concurs with the "Proposed AES Procedures for the Review of Environmental Impact Statements" prepared by APCO and would suggest that the role of this proposed office should be broadened to include environmentally related matters such as the following:

- Coordination and/or preparation of AES inputs to various government contingency plans to deal with environmental emergencies such as an oil spill.
- Coordination and/or preparation of Environmental Operating Conditions (EOC's) in the approval process for projects that create environmental hazards related to air quality, and projects that require environmental observation and prediction systems.
- Coordination or undertaking monitoring/surveillance, periodic or final evaluations; preparation or coordination of various reports related to monitoring.
- Coordination of AES inputs to various environmental documents that require statements of standards in air quality, environmental observation and prediction systems.

AIR QUALITY ACTIVITIES - CENTRAL REGION

H.M. FRASER
Scientific Services Division, Central

ORGANIZATION AND STAFF

Regionally the Department of the Environment uses a system of standing technical review committees reporting to the RSCC to accomplish their aims in the Federal EARP process. Hugh Fraser is the Central Region representative on the RSCC and between them Hugh and Einar Einarsson belong to four review committees which address Mining, Transportation, Hydrocarbons and Contaminants. Membership on all is shared or alternated with Scientific Services staff of Western Region, an arrangement which maintains close communication with the complex departmental organization and not incidentally saves a good deal of travel money. Other Scientific Services staff are occasionally involved in supporting the committee members whose main function in this area is EARP review and review coordination.

Scientific Services undertakes considerable environmental work apart from the Fedearl EARP. This is connected with other Federal programs often in support of sister DOE agencies, and in the matter of advice to Provincial environmental agencies.

RECENT ACTIVITIES

Federal EARP continues to be the most demanding load.

- Arctic drilling (South Davis Straits, North Davis Straits, Lancaster Sound); the Arctic Pilot Project (LNG) and the Arctic Islands Pipeline Project (Polar Gas) present severe problems in inter-service and intra-service communication which avoid frustration only by the patience and fortitude of all involved. In the last year, we have had three major EIS

reviews and innumerable meetings and phone consultations.

- Federal EARP is well involved in the uranium mining and milling development in Saskatchewan. Some 150 companies have entered the field and several projects have surfaced through the RSCC, including Key Lake, Cluff Lake, Mid West and Eldorado Warman.
- Expansion of the Tar Sands projects (Alsands, Imperial Cold Lake) is being felt in Saskatchewan. Through the RSCC we are being called upon to support the Province and DINA with our main concern being the transport of air pollution into Saskatchewan.

Coal is a popular fuel for power generation on the Prairies. The Poplar River plant at Coronach, Saskatchewan, a stone's throw from the U.S. Border, will go into operation within the next year and continues to be an international issue. The report by R. Portelli several years ago is a major assessment of this situation; we continue to offer intermittent advice regionally and are negotiating for a weather station at the plant. Methodology from Headquarters studies has allowed us to prepare studies for older and smaller thermal plants in Manitoba; we also eye with some apprehension the steady expansion of the large plant at Boundary Dam in Saskatchewan which had quadrupled in size in the last 15 years with no known second look at its emissions.

The AES was on a regional task force to review many plans concerning a Manitoba Hydro nuclear plant; this activity has now been shelved since the project does not appear to be needed before the 1900s.

There are two very large smelters in northern Manitoba and we are called upon for advice concerning their pollution several times a year. The first large Arctic mill - at Strathcona Sound - has been fairly quiet with only minor attention occasionally being needed through the RSCC. We have

recently provided advice on winds to Saskatchewan regarding an industrial park and an existing steel mill at Regina.

Agricultural problems, like the industry, tend to be widespread and not large on an individual basis; an exception is the Simplot Chemical Company plant in Brandon regarding which we provide consultation from time to time. Nevertheless, the problems with agriculture can be severe as in the case of anhydrous ammonia which is an increasingly popular fertilizer. There have been three serious incidents in Manitoba in the last two years due to ammonia leakage and in a recent case, we supplied considerable support to Federal and Provincial environmental agencies regarding relocation of a supply depot. Feedlots, because of intense odor problems, are another agricultural application which crops up occasionally. Agricultural burning is a recurring phenomenon in the Fall which has not been seriously addressed as an air quality problem despite the disastrous situation which we reported on extensively in 1977.

No doubt other airports in Canada are facing problems because of incinerators required under agricultural regulations and being handled under Federal clean-up programs. For the past year, we have been heavily involved in the planning for such an installation at Winnipeg; the main problem is the large amount of water vapour emitted.

PROBLEM AREAS AND SUPPORT NEEDED

We have already mentioned the difficulties in developing a reasoned and reasonable environmental position in the bureaucratic jungle of Federal EARP; to our mind, this is the greatest problem facing this process today. The establishment of an environmental office at Headquarters is a welcome step to assist communication within AES where several Headquarters components are called upon to support as many as four regions. However, we believe the main problem exists in departmental coordination of divergent opinions from widely separated agencies which must then pass several levels of further time-consuming review. The DOE must improve the current process

which, in our opinion, is strikingly inefficient and of unknown effectiveness.

Baseline data: do we have enough or would we ever have enough? In the remote areas the answer to the former is clearly no but progress in establishing new stations and sources has been uneven. It seems that if the climate can be shown to threaten an Arctic operation, funding is obtainable, for example, for the Beaufort Sea and Eastern Arctic prediction systems. If the threat were solely environmental, there is some question as to whether any help would be coming for baseline weather information.

In remote and Arctic areas, Central Region expertise is often inadequate; the best examples are sea/ice state and air quality. This lack will be overcome only very slowly if at all and we will require continued Headquarters support. Although there have been notable advances in the Region in the more common air quality problem areas such as the transport and dispersion of sulphur dioxide, our recent activities reveal specialized and sometimes localized problems which could be handled regionally if the expertise can be acquired. This acquisition depends partly on the availability of Regional resources and partly on the ability of Headquarters to supply appropriate methodology and support. Some pollutants of interest are as follows:

- radioactive gases and particles
- water plumes
- ammonia
- agricultural pesticides, herbicides and fertilizers
- odors
- noise

The long-range transport of air pollution is of particular interest in two developing fields. The number of plants extracting oil from tar sands or other deposits will steadily increase and their accumulative effect on downwind areas must be addressed. The second situation is that of the coal fields of the Northwestern U.S. plains which are expected to be the scene of massive electrical power generation. This

coming development has been rumoured for some years and with the growing crisis in that country, might be thrust upon us very suddenly.

TECHNOLOGY TRANSFER

The Air Quality Course given in Headquarters in 1972 formed an effective base for the air quality expertise which now exists in Central Region. We strongly support such courses and have several comments.

- A base course (1972 and this week) is not needed every year but if the time lapse is more than five years, it may lead to problems because of changing staff in the regions.
- Special problems (water plumes, radioactivity, etc.) could profit from short sessions in other SS meetings.
- Short on-site regional courses with Headquarters support are desirable. They are more efficient in reaching many people.

There will always be situations which because of their size, their international implications, or special nature, require that they be under a Headquarters lead. The reports arising from these - and we have four large ones in Central Region in the last few years, are major reference works to us and form the second most important component of our regional expertise.

The ongoing dissemination of new methods by the provision of copied articles, reference lists, computer programs, etc. from AQRB is desirable. Computer programs are of particular interest. In the long term, a dial-up service which will link the regions to the latest programs and the data banks avilable in Headquarters looks very promising. In the next few years however finances will be a constraint and Headquarters might better provide us with copies of programs adapted to regional computer systems.

FUTURE

Some of our pressing needs will be to develop expertise in the application of meteorology to uranium mining and milling, coal burning power plants and the extraction and transport of hydrocarbons in the Arctic. A certain uneasiness continues over the possible emergence of problems from the increased use of spray chemicals in agriculture.

We expect that our ability to interface with coal and uranium problems in Saskatchewan will be improved by the expansion of the Scientific Services office in Regina. The dedication of part of a man year to air quality and environmental assessment in that office will also take some load off the regional SSD in Winnipeg.

AIR QUALITY ACTIVITIES - ONTARIO REGION

R.G. LAWFORD
Scientific Services Division, Ontario

INTRODUCTION

This report reviews the activities of the Ontario Region Scientific Services Division (SSD) in air and environmental quality programs during the past three years. The possible activities in these areas during the next two year period are also described. Finally, based on our experience, a number of problems are identified and solutions are recommended.

In the Ontario Region SSD, air quality activities are carried out in support of two of our three main goals. In particular, these activities are carried out to:

1) support the Regional Director in regional inter-Service programs. Activities in this area are related to either long-term departmental programs or one-time high-profile departmental projects,
2) provide climatological data, consultation, applied research and other specialized non-forecast services for users.

2. PAST, PRESENT AND FUTURE INVOLVEMENTS IN LONG-TERM DEPARTMENTAL PROGRAMS

2.1. The Past and the Present

Departmental programs under this heading include the Environmental Assessment Review Process (EARP), the Environmental Contaminants Programs and the Aquatic Environmental Quality Program (AEQ). These programs are coordinated through the Regional Screening and Coordinating Committee (RSCC) in the case of EARP; the Regional Environmental Contaminants Committee (RECC) in the case of the Environmental Contaminants Program, and the AEQ-Regional Coordinating Committee (AEQ-RCC) in the case of the AEQ program.

During the past two years the Ontario Region SSD has made several major contributions to the Ontario RSCC. During that time OAESA has coordinated and made major contributions to reviews of four Environmental Impact Statements (EISs). Although these four reviews all involved a single industrial project, the construction and operation of a uranium hexofluoride refinery by Elorado Nuclear, each one relied on different climatological data bases and different mesoscale meteorological processes.

The SSD also provided chairmanship for the RSCC during a four month period. This activity involved OAES, in conjunction with lead agencies, in developing positions and preparing responses to proponents regarding environmental impacts for a variety of projects including the construction of a crossing for an abandoned portion of the Welland Canal and a proposed ARDA project for improved drainage along the South Nations River. In addition, OAES organized RSCC meetings, prepared reports for the Regional Board and participated in a RSCC chairmen's meeting. SSD staff also participated in meetings, and in the reviews of a number of reports, and contributed to a major review of DOE Involvements in EARP and to inter-disciplinary environmental studies such as "Ottawa Airport - the Environmental Setting".

The Ontario Region Environmental Contaminants Committee (RECC) was set up in 1977. OAESQ and OAES have provided AES membership on that committee. Initially, in conjunction with the EPS and EMS representatives, OAES assisted in setting up the committee's structure. Two working groups were formed and assigned tasks. The groups dealt with organic and inorganic contaminants. They were expected to identify and document the characteristics of environmental contaminants of major concern in Ontario. In addition, the RECC reviewed a number of proposals for the Environmental Contaminants Contract Fund (ECCF). Unfortunately, the Ontario RECC lost its original chairman in December 1978 and since that time has been inactive. The fact that all proposals from Ontario

Region DOE Services for ECCF funding were rejected has likely contributed to the present letdown.

AES was represented on the AEQ-RCC by OAES. This committee is responsible for coordinating laboratory facilities, field programs and for approving major capital expenditures for equipment. To date, the committee has reviewed several proposed equipment purchases and prepared an annual field projects report. A second report on the DOE field projects is expected to take place in Ontario in 1979-80 is currently being prepared.

2.2. Future Involvements

The future involvement of the Ontario Region SSD in established inter-departmental programs will likely remain at the same level as it did for the first half of 1978. The Polar Gas Pipeline project is the only major EIS review expected in 1979-80. The number of other projects that are carried out by the RSCC will likely be dependent, to some extent, on the responsibilities that the new RDG assigns to the RSCC. During the next two year period the SSD intends to increase its internal capabilities for assessing air pollution problems. This will be done by modifying and implementing local and regional dispersion models and by increasing the variety of data and information bases on air quality and environmental impacts available in the region.

Activities related to the RECC are expected to increase in the next few months after the RDG consolidates EMS and EPS contaminants activities. The Ontario Region SSD intends to submit one or two proposals to the ECCF during the coming year.

3. PAST, PRESENT AND FUTURE INVOLVEMENTS IN HIGH-PROFILE DEPARTMENTAL PROJECTS

3.1. The Past and Present

The major Ontario Region SSD involvement in this area resulted from a Regional Board decision to make a contribution

to the Ontario Royal Commission on Power Planning (known as the Porter Commission). As a result of this decision, the Ontario Region, SSD, with support from the CCC and AQRB, prepared a Chapter for a report entitled "Electric Power Production and Transmission in Ontario from an Environmental Perspective" as well as two supplementary reports for the Porter Commission. One supplementary report contained a review of the relationships between electrical energy and climate. The second report examined the types of climatic stresses that would be experienced by solar and wind energy systems located in major Ontario centres. In addition, OAES along with experts from the CCC, testified at the Porter Commission hearings.

The Ontario Region has also contributed to DOE emergency planning for environmental emergencies. Publicity and requests for information resulting from the Harrisburg, Pennsylvania nuclear power plant incident have made the Region aware of its need to develop a capability for responding to emergencies of this nature.

In addition, SSD personnel have contributed to DOE Ontario Region by participating in the EMS task groups on emergency, consulting with CWS on baseline studies, etc.

To date, the Ontario Region SSD has not made a contribution to LRTAP.

3.2. The Future

During the next two years the Ontario Region SSD intends to implement regional transport models for use in asssessing environmental emergencies in both historical and real-time modes. Special attention will be given to the transport of radionuclides. In addition, we hope to become more involved in CWS/CFS/LD baseline study projects and in special projects initiated by the new RDG. We also intend to explore the possibility of contributing to the Ontario Region LRTAP activities.

4. THE PROVISION OF METEOROLOGICAL DATA, CONSULTATION AND APPLIED RESEARCH FOR USERS

4.1. The Past and Present

The Ontario Region SSD made a significant contribution to the AES Nanticoke field study in 1978. An on-site weather office was established at Nanticoke for the duration of the project. The meteorologist and technician at this office provided specialized forecasts, morning and evening weather briefings, a continuous weather watch and an hourly observational program. After the project was completed a report containing maps, observations and a description of the synoptic conditions on each day was prepared.

In addition, a second report entitled "A Synoptic and Climatological Study of Conditions Associated with Poor Air Quality in the Nanticoke Area During the Year 1975, 1976 and 1977" was prepared. This report describes the meteorological conditions that are most frequently observed on days with poor air quality near the Nanticoke Fossil Fuel Plant.

Over the past three years the Scientific Services Climate Unit has provided data to a number of users in OME and in the private sector for use in air quality studies. The Division's application and consultation unit has also provided consultation to a number of users regarding air pollution problems.

During the summer of 1978, a summer student prepared a draft report summarizing the climatological information and data sources available for agencies carrying out assessments of the impact of industrial developments on air quality.

4.2. The Future

The Ontario Region SSD will continue to provide support to AQRB studies carried out in Ontario and to users such as OME who request support. For example, the Ontario Region intends to operate a one-man weather office during a three-week OME field project at Nanticoke in the Spring of 1979. In

addition, we plan to increase our ability to respond to users problems by increasing expertise within the SSD and by implementing more air quality models in the Region. This will be accomplished by participating in more in-depth research projects and by having SSD personnel attend air quality conferences and workshops.

5. PROBLEMS AND RECOMMENDED SOLUTIONS

In the past three years AQRB has assisted the Ontario Region in many ways. The Ontario Region and particularly the SSD is most appreciative of this support. However, Ontario Region SSD activities in the field of air quality are frequently not as effective as they could be. The following paragraphs outline some specific problems. Furthermore, I have recommended solutions that could help us solve them.

5.1. There is a lack of regional expertise, data bases and policy statements related to environmental impact assessment. Consequently, proponents can present information in EISs and we are unable to carry out an adequate assessment because we do not have similar data or models available to us.
Recommendation: AQRB should provide more technical support to the Regions by providing documented dispersion models, climatological dispersion models and regional transport models for implementation on region HP mini-computers and by setting up joint projects with the Regions. AQRB should seek more regional involvement in programs such as LRTAP, environmental assessment and environmental contaminants at both the planning and execution stages.

Furthermore, AES should undertake an analysis of all environmental and societal issues that are, in any sense, weather related. As part of that analysis they should formulate an AES position relative to each issue and assist in formulating DOE positions on the same issues. Our positions regarding these issues and the background analysis used to arrive at these positions, should be published and made avail-

able to all SSD staff participating in the reviews of EISs, regional plans, etc. A sample position in the final report could read as follows:

> "The AES favours nuclear energy power generation over generation systems that rely on fossil fuels because ...."

5.2. AES participation in regional committees is often hampered by the lack of clear terms of reference for many of these inter-Service committees. Often this results from a lack of agreement amongst regional DOE managers on the roles and responsibilities of the Department. A few of the specific questions which appear to be unresolved in the Ontario Region are:

- What are our responsibilities for consulting and providing other support for a proponent or consultant who is carrying out an environmental assessment (either or inside or outside EARP)?
- What are the responsibilities of Services versus inter-Service committees for environmental assessments being carried on outside EARP?
- Who should take the lead in assessing the quality of data and analytical methodologies related to environmental contaminants problems and in maintaining an inventory on current research programs - the RECC or the AEQ-RCC?

Recommendation: AES, through the SSDs, should take a more active role in regional inter-Service environmental programs and baseline studies. AES management should seek to encourage senior DOE management at both the HQs and regional levels to clarify the roles of these committees and the role of the AES within these committees. Upon clarification, AES personnel should be advised of these roles and, where appropriate, should be encouraged to take leadership in the committees. As part of that leadership role, AES should strive, wherever possible, to simplify processes such as EARP and to

reduce the levels of bureaucracy involved in these processes.

5.3. AES does not have viable research programs in areas where our sister Services need support (e.g. environmental contaminants, transmission of noise in the atmosphere, etc.).
Recommendations: The AES contaminant program and other environmental programs should be reviewed in the light of regional requirements and, on the basis of this review, they should be funded to a level where they can respond adequately to the regions and to other Services. Furthermore, AES Regions should be involved in reviewing and recommending modifications for the planned research programs of AQRB and they should have a voice in determining which programs receive funding.

5.4. AES does not and, on occasion, cannot monopolize on opportunities that arise in the Regional Board or at subordinate committee meetings for participation in all activities related to air quality due to a lack of regional expertise and on many occasions a dearth of information on AQRB activities. LRTAP is a major problem area. At present, there is no representation by AES Ontario Region on any LRTAP committee. Furthermore, AES Ontario Region was not invited to participate by having projects in this program. At the Regional Board level the roles of EPS and EMS are highlighted while AES is virtually ignored.
Recommendation: The Regional Chief of Scientific Services should be given observer status on the Regional Board and act as the Deputy Regional Director in activities involving the Regional Board. This would allow the Regional Chief to assist the Regional Director in identifying areas where SSD support should be granted because it would allow the AES Region to make a larger contribution to DOE programs. Furthermore, AQRB should make every effort to involve the Regional SSDs in projects such as LRTAP and the Great Lakes Water Quality Agreement, and, in the case of the Ontario Region SSD, in activities or meetings in which AQRB is liaising with Ontario Region

DOE Services and other Government Departments or OME or other Regional or Municipal Agencies in Ontario.

5.5. OME and AQRB both have large capabilities for providing consultation and support in air quality. Frequently, the Ontario Region SSD is not even consulted nor contacted when users bring regional air quality problems forward to AQRB for solution. This lack of contact with the users prohibits the Ontario Region SSD from developing its air quality capability.

Recommendations:

5.5.1. Additional resources be granted to the Regional SSDs to support its environmental activities. These resources could come through either the reallocation of resources within the Regions, within FSD, within AES, or within DOE. Perhaps they could also be acquired through a new HQs/Regional submission to Treasury Board.

5.5.2. ACEC should develop a course for meteorologists seeking to obtain positions in SSDs. This course would provide training in air pollution meteorology and research methodologies.

5.5.3. AQRB should expend resources on technology transfer (i.e. for documenting models and for transferring these models to the Regions). Furthermore, AQRB staff should refer routine regional requests to the relevant Region for action and should copy the Regions with their responses to all requests for advice or assistance that they receive.

5.5.4. Regional AES staff should be the principal AES representative on all regional committees involving air quality.

5.5.5. AQRB should place a higher priority on responding to requests for advice and support from regions.

AIR QUALITY ACTIVITIES - QUEBEC REGION

G. Desautels
Scientific Services Division, Quebec

Up to now, the involvement of the Quebec Region in air quality activities has been limited to paper work through our participation in committees related to LRTAP, CONTAMINANTS or EARP.

The most frequent request addressed to us is to comment on impact studies for different projects. These studies, apart from the climatological section, always contain an air quality section in which dispersion of pollutants is estimated. In view of the limited amount of information which appears in those studies, we feel it is desirable that guidelines be issued by AQRB with regard to the methodology that such studies should follow. We find very frequently statements such as:

> "During the Arctic summer when there is constant daylight the atmosphere will be much more unstable and turbulence levels associated with Pasquill's categories C or B will occur."
>
> "Extensive field studies funded by the Central Electricity Generating Board in England and by Tennessee Valley Authority in the United States have shown that fumigation situations should not produce average concentrations higher than the effects of normal diffusion in a homogeneous atmosphere (Lucas 1975b)."
>
> "At worst, the presence of a trapping layer has the effect of doubling the maximum ground-level concentration that would have occurred in a neutral homogeneous atmosphere at the same wind speed."
>
> "Fortunately, it appears that the use of the Gaussian distribution does not introduce any significant errors into diffusion calculations (Islitzer et al. (1968))."

"In summary, it appears that it may be conservatively assumed that the effects of terrain are such as to increase the maximum ground-level plume concentration during neutral atmospheric conditions by about 50 percent over the value expected for flat terrain. Under unstable atmospheric conditions, the available evidence suggests that terrain effects are negligible, while during stable atmospheric situations, the effects of terrain seem to be beneficial."

These statements, once written in the impacts studies are taken for granted without any other proofs and we, at the Region, are not competent enough to reject it. There is a need to compile in an ordered form, the principles that are accepted and the ones that are rejected. In our point of view, if it is not done, there is a good chance that such statements be interpreted differently across the Regions, position which will put AES in a difficult situation.

The facts above illustrate the need to establish an official procedure for the reviewing of impact studies in the field of air pollution dispersion.

The second most frequent request is a meteorological one connected to diffusion process. People want to know the exact stability and wind conditions over a populated area or an important industrial complex. Unfortunately, it has been impossible in the past to answer these requests although they dealt with the parameters normally identified as an AES responsibility. We think that we should establish a network to measure such values and equip the Regions with the necessary material to do it. To our knowledge, such data has been taken only for research purposes and we think it is time that we start to do regular observations and issued bulletins.

As an outlook for the future, we see the need to develop national programs in order to get resources and be able to develop regional competence. Otherwise, air quality will remain like it is now, a ton of good will and an ounce of resources.

AIR QUALITY ACTIVITIES - ATLANTIC REGION

E.W. BRANDON
Scientific Services Division, Atlantic

INTRODUCTION

The Atlantic Region has not to date experienced intense industrialization and the resulting air quality problems to the same extent as have some other Regions. Even so there are several localities in this region where air quality problems do arise.

Prior to the acquisition of regional minisonde equipment field studies were carried out by ARQD at Saint John, New Brunswick and Canso, Nova Scotia. The latter location experienced a sudden influx of industry in 1974 which caused EPS and the Nova Scotia government grave concerns over the potential impact of the new development on the air quality of the area. EPS in turn requested ARQD to conduct a meteorological air pollution study. The Coleson Cove plans for a generating plant upwind of Saint John, New Brunswick, were instrumental in causing the New Brunswick government to request an air quality study of that area. Subsequent to obtaining regional minisonde equipment in 1976 the SSD has coordinated with the Air Quality Branch of EPS in carrying out field studies related to air quality.

RECENT AIR QUALITY ACTIVITIES

The SSD Atlantic's involvement in air quality activities in recent years is outlined in the following.

1) Input to the Coleson Cove Supplementary Control System.

Discussion involving representatives of EPS Atlantic, ARQD, SSD Atlantic, New Brunswick Electric Power Commission and MacLaren's began in 1974 in order to develop a supplementary control system for the Coleson Cove Generating Plant then under construction. The plant came into production in 1976 as a 1000MW, oil-fired, 3 unit station located at Coleson Cove, 10 miles southwest of Saint John. The generating station incorporates a 600 ft. stack with selective fuel burning to reduce gaseous emissions and and resultant ground level concentrations of sulphur dioxide.

Electrostatic precipitators are being installed to remove 90% of the particulate matter emitted.

The certificate of approval for the station gives the following major guidelines for operation of a supplementary control system:

a. For onshore winds the maximum allowable concentration of sulphur dioxide under normal conditions:

450 $\mu g/m^3$	(17 pphm)	over 1 hour
150 $\mu g/m^3$	(6 pphm)	over 24 hours
30 $\mu g/m^3$	(1 pphm)	over 1 year

b. For onshore winds under conditions of breakup of a low level inversion and during persistent advection inversions:

900 $\mu g/m^3$	(34 pphm)	over 1 hour
300 $\mu g/m^3$	(11 pphm)	over 24 hours

c. For offshore winds under all atmospheric conditions:

900 $\mu g/m^3$	(34 pphm)	over 1 hour
300 $\mu g/m^3$	(11 pphm)	over 24 hours
60 $\mu g/m^3$	(2 pphm)	over 1 year

In order to comply with these criteria the Supplementary Control System had to include a predictive computer model of atmospheric dispersion. The Computer model is based in large part, on the early work done by the Tennessee Valley Authority for their coal-burning power plants.

AES Atlantic was asked to supply the wind forecasts out to 24 hours for the system. After some thrashing about, it was decided to obtain the Danard Model, a fine mesh diagnostic model designed by Maurice Danard, which describes the influence of topography and surface heating on surface winds. The model requires for input 850 and 700 mb temperatures and forecast surface temperatures at a reference station. The model was adapted to the Hewlett-Packard minicomputer by the Maritimes Weather Office staff under direction of the ODIT Unit, while the technique for supplying surface temperature forecasts was supplied by the SSD using a statistical routine.

The supplementary control system has been fully operational for the past two years or more. The required meteorological input is obtained by the power company from the MWO minicomputer on a cost recovery basis. The second alternative to such a

system is to burn low sulphur oil on a continuous basis which is not only prohibitively expensive but is probably impractical due to supply shortages, especially during the winter heating season.

2) The Lingan Field Studies.

In response to the need for additional power generating capacity in Nova Scotia, the Nova Scotia Power Corporation is contructing a coal burning electrical power generating plant at Lingan on the coast of Cape Breton, about 15 km northeast of Sydney. The terrain surrounding the plant site is essentially level and presents no features to seriously interfere with plume dispersion.

The initial development at Lingan is planned to be 300MW or 2 x 150MW generating units. The first stage will be provided with a single 152 metre stack. Future availability of coal supplies will be the deciding factor in limiting future development. The second stage of development will probably be, at most, 600MW or 2 x 300MW generating units with a single 152 metre stack.

Sponsored by EPS, five joint EPS-AES field trips were made to Lingan to gather air quality data utilizing portable SO_2 monitoring equipment and the AES minisonde equipment. These studies took place during the following periods:

(1) February 15 to 24, 1977
(2) March 21 to 25, 1977
(3) August 21 to 26, 1977
(4) October 20 to November 2, 1977
(5) June 12 to June 20, 1978
(6) January 24 to February 3, 1978

The minisonde data were processed by the SSD and synthesized in a report presented to EPS along with copies of the processed data. No doubt further work will be done at this site when the generator goes operational. The plant is scheduled to fire up very shortly. The first unit will go into the grid in November, 1979, with the second unit entering the grid in November, 1980.

3) Local Minisonde Studies.

There is a requirement in the Halifax area for temperature

lapse rate and wind data. In order to fill this gap minisonde data were collected in the vicinity of a power generating plant in Dartmouth during the periods October 16 to 31, 1978, January 22 to 25, 1979, and March 5 to 9, 1979. EPS personnel collected data on SO_2 ground level concentrations downwind of the plant coincident with the minisonde studies.

It is planned to continue this study in the local area at intervals throughout the year until a reasonable amount of data has been acquired.

4) Long Range Transport of Air Pollutants

Dr. Des. O'Neill, Chief of Scientific Services, is Chairman of the Atlantic Region Long Range Transport of Air Pollutants Technical Committee. This committee has from the outset invited representation from provincial, as well as federal, agencies. A workshop is currently being planned by the committee to be held in Halifax October 17-18, 1979, on the theme "Impacts and Effects of Long Range Transport of Air Pollutants in the Atlantic Provinces".

5) Canso Studies.

There are eleven major point sources and one area source of sulphur dioxide and/or hydrogen sulphide in the Strait of Canso area. These sources include space heating, a 1000 tons per day pulp and paper mill, a 320 megawatt thermal electric generating station, a 100,000 barrel per day petroleum refinery and a heavy water plant. The total emission of sulphur dioxide from all sources is 1240 gs^{-1}.

Interest in the air quality of this area prompted a recent joint SSD-EPS effort to estimate the mean monthly and annual concentrations of sulphur dioxide for the Canso area utilizing the Climatological Dispersion Model stored in the Cyber at Dorval. An attempt was made to modify the meteorological input to the model to take topography into account. The results of this work were presented to the Nova Scotia government as a report and in addition were accepted in modified form for publication in a journal.

DISCUSSION/COMMENTS ON REGIONAL PRESENTATIONS

P.G. ABER: I note that in all the regional presentations there were either direct or indirect references to a requirement for additional training in relation to air quality environmental assessment processes. I wonder whether it would be possible throughout the discussions that are taking place here to perhaps identify more specifically what these requirements are. I would like to inform you that preliminary contact has been made between training branch and the air quality branch to discuss this very subject, and the type of requirement that I've been hearing seems to be on two levels; that there is the sort of program that Hugh (Fraser) indicates that's going on that deals directly with models, and the establishment of expertise in the people who are going to be participating in this program, and there is the other type of requirement that Rick (Lawford) identified in terms of background information or people who would be hoping to follow a career in the scientific services division. It would be most useful if Field Services could identify the type of requirement that is seemed to be general, so that the Downsview units in training branch and air quality could get together and devise the type of courses that would be most useful.

R.V. PORTELLI: I'd just like to get into something which will probably be discussed more later, but it arose in two or three specific presentations. Rick Lawford for one, identified documentation of user models and in the technology transfer requirement. Hugh Fraser also mentioned this possibility. Some work has been done on this, and we have yet to receive response to a modelling user's guide on rudimentary Gaussian modelling formulations. I wonder if this type of thing has been utilized just for the purpose of letting us know whether this is the direction we should be going in. We'll get into it heavily later but I'd like a response at this time to that question.

R. LAWFORD: We have, as you know, taken one or two of the dispersion models, Ron, and implemented them in the Ontario region. We have not been responding to requests from users by using those models, but it was my understanding, and I'm going to turn it back to Steve (Lapczak) to correct me on this, that the documentation that was provided with those models was quite adequate, (and I'm a bit hazy now because it's some time since I looked at it), but any information that can be given on the limitations of the interpretation of the results of the model is very useful. Steve, do you have anything to add to that?

S. LAPCZAK: In that particular case there were three models, and the way we were implementing it, we put the third one on an HP, and I think, Ron, you agree that it would take 24 hours to run it on the mini-computer. Out of the three of them one couldn't be used at all. We got the first two basically working. There are still a few bugs in it, but we haven't had any real users to try it out on. So, we sort of got it up to a certain stage and left it. Documentation came with those particular three, but those are the only ones we've ever seen.

E. EINARSSON: I'd like to mention our experience with those same three models, the point source dispersion models. We have used all three of them. We've had about four occasions to use them, with both our own needs in connection with the Arctic Pilot Project and other things that we were checking out, and also user requirements with the Province of Manitoba. We have run the third model, as mentioned there on our HP and it doesn't take all that long. There must be some bug in the one that Ontario region is using.

PANEL/PLENARY DISCUSSION ON AES HQ/REGIONAL LIASON AND HOW BEST TO HANDLE AIR QUALITY PROBLEMS

PANEL CHAIRMAN: J.W.S. Young

PANELISTS: R.E. Munn, A.D. Christie, H.L. Ferguson, H. Fraser, S. Nikleva, R. Lawford

QUESTION 1 (J.W.S. Young):
In 1985 AES has a goal of total environmental prediction. This involves the forecasting of environmental parameters which have socio-economic significance and which are due to the march of meteorological events. To what extent do you see the need for this type of forecasting? In the form of air pollution potential only, stagnation forecasts, or real time air quality forecasts? I'd like to first get an outsider's view of this, so Ted, could you give us your thoughts in two minutes or less.

R.E. MUNN: That's a big question; I think it's better to try and be specific with one example, and each example might be different, but let's take the acid rain case. AES in the long-range transport program has a big, very big departmental program, and involves other departments, and I'm sure you're doing a fine job on research into long-range transport and acid rain effects all the way from the sources to the receptors to the effects, but my view is that this is a useful research study, but it may be answering the wrong questions. In other words, it may be solving problems, but not the right problems, and I would argue that one, at the very outset, should bring in the policy analysts and the socio-economic people, the human perception people and the economists to give you the framework for governmental and intergovernmental actions that can be taken, and they should be telling the research people what kind of questions they want answers to. The questions they want answers to may be ridiculous, but at least that's a starting point and then you can go back and tell them they're ridiculous, and you start negotiating some on middle ground, but for example, it may be that some of the research that Harold Harvey is doing on the number of years left in buffering capacity of the lakes in the Laurentian Shield, and he's measuring this in terms of 25 years to 1000 years, and it may that it doesn't make any difference whether the number of years left is 50 years or 60 years. That may be an unimportant question for the policy analysts, because it's a second order kind of thing, so that, I think there's an overall framework within which these environmental problems should be couched, and then that will lead to research which is kind of mission oriented.

J.W.S. YOUNG: Ted's brought up a very interesting point, and that is that we're trying to address here how AES as a whole should handle air quality problems to meet the general needs of the community. I think before we embark on any problems, it's important, as Ted says, to decide what the community wants, and from that perspective, perhaps one of the regional representatives might like to address this question.

R. LAWFORD: I suppose one reason why we haven't got into this business more is because the need isn't there, or it hasn't been demanded by the public that we provide this type of forecast. Possibly in Ontario there is a reason for that,

in that the Ontario Ministry of the Environment has their own forecast office, and in fact delivers some of these products that are listed here, and so they have met the needs. However, that is a good point. I suspect there are other areas for environmental predictions where we could start delivering services, maybe not in terms of stagnation forecasts, but possibly special modules could be attached to a lot of our prediction models to forecast erosion, to determine when there are going to be ozone episodes in southern Ontario, so that farmers could be advised. Special forecast services that might be delivered through a special type of outlet, perhaps an agriculture weather services outlet in the case of ozone episodes, but we do need to do a survey of what the user needs are before we start out on any major thrusts along this line. It's a good point that we don't know what the users want.

A.D. CHRISTIE: When we talk about total environmental prediction, I think it really relates to what we are in a position to predict. If we're talking of what we know of in terms of real-time data and if we have the capability to do the kind of forecasting which gives us some kind of real time output so that to address some of the specific questions: Things like real time air quality forecast. This is something way in the future because we simply don't have the network set up or the communications that are required to make the kinds of observations that are needed for air quality predictions in so far as they come into total environmental prediction. But this doesn't mean to say that we can't give something that amounts to real time if we approach things again from the synoptic point of view. We can identify situations where we think conditions are likely to be bad and this is a different kind of forecasting, maybe something of a scenario-type forecasting. It relates to an identification of conditions like the air pollution potential and certain circulations that can be identified as circulations that you have to be careful about. I think that should go into this total environmental prediction package.

H.L. FERGUSON: I'd like to take the view that AES has a responsibility in the sense of bringing the perception of air quality problems forward to the Canadian public, and to enhance that, I think that we should take a somewhat aggressive approach, while being conscious of the provincial sensitivities and the overlap between responsibilities, and being careful not to get into jurisdictional problems, but I don't feel we would be getting into jurisdictional problems by doing, on a routine basis, a forecast of regional air pollution potential, for example, not necessarily disseminating it to the public at large, in the initial phase, but at least making the information available, and then trying to stimulate interest and feedback on the part of the potential users. I think all of these are possibilities, but I agree with Al (Christie) that there is a kind of cascade of capability involved here, and that probably any expansion of AES activities in this regard would have to be interfaced to our capabilities at the moment, and what they might be 10 years from now. I would still see the AES responsibility as being largely on terms of a regional core service as opposed to site specific municipal air quality forecast, which I presume would still be a responsibility of the provinces, but perhaps using AES outputs as background information for that purpose.

R.V. PORTELLI: The U.S. have a system where they give out air pollution potential alerts or forecasts, and then they have 10 very stringent criteria which are used in ascertaining whether or not they put forward such an alert.

Now, in Canada, CMC puts out a stagnation forecast, and from what I can gather this is not utilized very heavily at the moment. Would any of the regional people feel that the route that has been used in the U.S. which is quite stringent, and I think requires in Canada the identification of the appropriate threshold values of certain parameters, would this type of scheme be amenable to the type of regional concerns we have, if any, or would an alternate proposal to that be acceptable?

R. LAWFORD: My reaction to that would be that, again, it's not clear what the federal/provincial responsibility is. I think in the U.S. it's a little clearer in that it's not state forecast offices that put out a forecast of air quality, and they rely upon the federally run state weather offices to deliver this type of service. Large scale maps such as those that are prepared by the CMC don't appear to be the answer, because in most weather offices I don't think they even display them, and a lot of the forecasters perhaps aren't even aware that they even come into the office, so that they're not really used to any large extent. Possibly if there were point or site specific forecasts, which would allow provincial governments who did not have their own expertise to make decisions as to whether they should take certain actions or not, it would be a product that they would be interested in. But in Ontario, again, the province seems to have the problem pretty well in hand, they've had about 5 - 10 years more experience in delivering a similar type of product.

R.V. PORTELLI: It appears to me though, and particularly in eastern Canada, and in conjunction with the long-range transport problems, that having this type of product (advisory) would be quite valuable considering the large loading now taking place in the eastern portion of Canada. Wouldn't this be, to people in the region, something that they would like to see come across?

R. LAWFORD: We would definitely like to see a product like that, but the question is "Would the province use it if it was produced, and if the province wouldn't who else in the province that is not connected with the provincial government, would use it?" Maybe we should throw this over to our Chairman, Dr. Young, to comment on the province's capabilities in these areas, and their needs since he was recently from there.

J.W.S. YOUNG: The provinces have a lot of needs; I don't think they really know what they want to do. I think it's up to us to perhaps direct them a little bit.

R.V. PORTELLI: I might interject there. It may be a matter of marketing what the capability potentially might be rather than just saying we haven't had a demand for it, and therefore we should assume that they're not interested in such a product.

R.E. MUNN: Well, Ron (Portelli) is perfectly right that AES has a good product, that the marketing isn't always that good, the research going on in the human perception area by some people in my institute, Ian Burton and Anne White, would suggest that the first thing you need to do is get a snappy title for your regional people. You're called the Regional Reps or the Scientific Support Units, or something like that, it just hasn't got the ring of a Dominion Observer or a Dominion Astronomer, or a Chief Oceanographer. In the United States they used to have State Climatologist, and that was somebody that

the public felt was a focal point for some services, and that's what we need, I think, and maybe you people have some ideas of what you should be called, but your present names aren't very good.

QUESTION 2 (J.W.S. Young):
The second question for your consideration is "What capabilities should AES have to deal with environmental emergencies, such as Three Mile Island? At what level should these capabilities exist? HQ? Regional offices? Individual weather offices?"

A.D. CHRISTIE: I think the experience we had with Three Mile Island illustrates some of the problems in dealing with an emergency that we haven't met before. We have all sorts of techniques available to us and a good deal of expertise, but there are two aspects of a problem that relate to an emergency. One is getting the right person at the right time to get the right answer, and the next one is putting it out to the media in a format that is useable to them. Now, the first part I think immediately, the offices, almost all of our regional offices, certainly the Maritime region and Ontario region were contacted directly by the media. They, in some cases, used their own initiative to give responses, in some instances they referred to us, and I know that ADMA's office in Ottawa was certainly contacted, and what is needed is some sort of recognized routine. Now I think we are in the process of the developing that, in fact there's a meeting tomorrow to discuss this kind of problem. But what I think we really need to talk of is an analysis of what techniques are available to answer different types of emergencies; again, the same kind of thing as we are dealing with with the regions, try and put something in a documented form so that it can be answered very quickly by the operational people, because this is an operational question, and then see if you can upgrade that as time goes on. This is where headquarters becomes involved. In the Three Mile Island situation, several of the regional offices were able to use hand-drawn trajectories. In relation to our long-range transport program, Marv Olson had developed a technique using the predictive fields or the fields from the Montreal office. So we were able to in a very short time, implement the trajectory model on the CMC computer and get an output from that. Now we were able to use this, but I doubt (Marv has doubts at the present time) whether this could be handed over immediately to be used in an operational sense, but it can certainly be modified so that it can be used in the operational environment. Now this is what should be done. Anything of that kind I would see, to answer this question specifically, should be answered by CMC. CMC are the people who have the computer capability and the techniques capability. They can respond all across the country with a kind of uniform product. Guidelines on how to use this information should come from some liaison office in headquarters. Then the improvement of a system; to improve it if we see what limitations there are in it, should be identified and that development work should go on. So, the regions should be the interface in my view, CMC because it is an operational service and because it is open 24 hours a day 7 days a week, should be carrying out the procedure and the research function here in Downsview should be to improve these systems so that we can make the best of what scientific knowledge we have here.

J.W.S. YOUNG: Do you think that since there are differences among the regions that it would be worthwhile for example, doing a study of all nuclear power plants and preparing, say, an emergency book that might have all of these forecasts already prepared, that could be used by Emergency Measures and various

other agencies who are interested in this.

A.D. CHRISTIE: Well, I would say that this depends on the nature of the emergency. In the situation, as in the case of Three Mile Island, you simply can't do this in advance; you're dealing with an atmospheric situation; you're using real-time data and in fact real-time prognoses. Under these circumstances, provided the technique is developed and can be put on line, there isn't much point in doing something in advance; you simply can't anticipate all eventualities. But there are other types of environmental problems that can be anticipated in advance, and the answer may be of a different kind. It may be of a kind that under certain circumstances, the response should be of a certain format. So I think there is a need to look at the different kinds of emergencies and analyze these.

H.L. FERGUSON: I think there are certainly some scenarios that could be described, where some kind of a case book or contingency plan or AES response plan, whatever you want to call it, could be described, and that would include the nuclear type of accident like Three Mile Island for example, as one class, another one would be the oil spill problem. There are various possibilities, but I would say by having a book which described the response to a number of different kinds of emergencies, that we would be making some advance over what we have available right now. Secondly, I would think that the response capability is closely tied to actually practicing response, and it would seem to me that if we have contingency plans in place that we should be having dry runs occasionally, perhaps by conducting quasi-military type exercises where we try to respond to a hypothetical emergency, just as a practise situation. That is about the only way I know of keeping up a capability of responding to environmental emergencies. I think the recent Kurdistan incident is a case in point. Very few of the lessons learned during the Chedabucto Bay spill a number of years ago were applied during the Kurdistan incident, because the people had changed, and they'd largely forgotten what was learned at that time. Another aspect of this whole question of course is that of jurisdictions. We continually run into this kind of question when you get into nuclear accidents for example, and whether AES should be involved in responding to public requests for information when the responsibility rests with the Atomic Energy Control Board in Canada for public information on that kind of environmental accident, and there is the responsibility on the part of the provincial agencies too. My feeling on that is that the AES should indeed respond within the framework of its own mandate which is for providing weather information of various kinds to the public, but I think that we need to discuss this with other responsible agencies to make it clear that we intend to move in this direction and to provide information within our own mandate as necessary. I think it is necessary, because AES is on the firing line in many of these situations, the regional offices are inundated with requests for information, and I think it's bad reflection on the federal government if these requests are turned aside or stonewalled, or seen as hiding environmental information. I think we should respond.

J.W.S. YOUNG: Do you see perhaps a split then, a joint effort on a local scale say around Pickering in the Toronto area, and perhaps an all AES approach to transport on a regional scale?

H.L. FERGUSON: Well, I think in the context of providing a contingency plan and getting people familiar with it within our service, that you could look at

the local problems as well as the longer range problems that might be involved in terms of putting forward the response that would be appropriate on the part of AES. I think this is a rather complex problem, and it's perceived as differently, of course, in Downsview than it is in the regions or in Ottawa, and there's a whole nest of responses in Ottawa to the same kind of emergency. For example, we had to get together in very short order a press release jointly with the National Health and Welfare. We had to brief the Minister of the Environment. We had to provide a briefing book for the Minister of the Environment, and all told in my own office we had about five man days devoted to that response. That took care of everything for the week more or less. We had to push other things aside, and it was really, again, an emergency type response.

R. LAWFORD: I would like to discuss this briefly from a regional point of view. In the U.S. there are regions which have designated an "emergency man" who goes on site when there is an environmental emergency, and my suggestion is that the AES could perhaps examine this method of handling environmental emergencies, where there might be models which have been developed at headquarters level in place in the weather centres or at CMC, as appropriate to the scale of emergency being dealt with, and that they "emergency man" would then be available to assist the forecasters in interpreting the results of the models, in answering the questions from the media, in dealing with the agencies who are wanting to make decisions on the basis of what the upcoming weather is going to do. I suggest that the case of the Three Mile Island raises an interesting point re the availability of technology in the regions. I understand the Ontario Weather Centre was interested in getting some results out of the long-range transport model, which is currently being developed by Marv Olson, and was told that it wasn't at the stage that they could provide numbers out of the model for the region, and yet when the Minister wanted results he got results from that very model. Now the question arises "What model is it that produces results that are good enough for the Minister that are not good enough for the regions?"

J.D. REID: I'd like to echo a little comment there of Rick (Lawford's). Last September I had the opportunity of going down to Lawrence Livermore Labs in California, and there they have been running for a couple of years now, a numerical model which they use specifically to deal with these emergency pollution problems. For example, they used it on the case where the Russian satellite came down in the Northwest Territories. As I understand, one of the big features they identify as being necessary in that sort of model, for running that sort of model, is to have someone who understands the model there, at the site of operations, to get the information that goes into that model. You can't do it just with the regular meteorological network and expect to get very useful results out. Although I agree with Al (Christie) that we should have a national centre, such as CMC to apply that model, it really takes a good deal of local input on the specific case in point, to input to that model so there is a definite need for a regional man, if you like, to have a knowledge of the model and have a knowledge of the input that is required.

H. FRASER: I'd like to add to what Rick (Lawford) and John (Reid) have said here about the regional aspects. I think Pickering would be a poor example, because it happens to be very close to this large body of international experts we've heard about, but perhaps Winnipeg is not, and I think of a nuclear

plant 60 miles northeast of Winnipeg. Now what happens if we have an accident there? I don't think in this case that a CMC model is the appropriate model for the quick response that you're going to have to have, and that response will be demanded by the media from the local weather office. That's what it's going to be; it's not going to be something higher; what's who they'll hit first. Now they can shuffle it up the line a little bit, but somebody in the region is going to have to be there, and I like the idea of the emergency man who's on the site, and knows what the model is about, and possibly that's something that could be supplied by scientific services in the region, because something has to be done about a local scale forecast; that's local in time and space. That isn't going to be possible on the type of models that are run at a national centre. You're still going to need the local forecaster to get out what's needed for the quick response in the area. Three Mile Island is a little different. That's happening somewhere else, but what if it's happening right here? I think you must have some local capability as well as a national capability.

A.D. CHRISTIE: I think it depends on the nature of the question you're asking. In the situation with Three Mile Island, you're looking at the effects somewhere around 20, 30, 40 kilometers from the site. If it's happening right in Canada, if it's at Pickering, this isn't going to give us the kind of answer that we need. Then we're down to closer range models. We're down to dispersion type models again. Now that is a different question. These are the kind of models that we should be developing here and putting into packages for application in the region. What I'm talking about in the situation in Three Mile Island is something which is still going to have significant effect at a considerable distance from the site of the problem, and there we really have to resort to CMC because they're dealing with the kind of scale there that is equivalent. The prediction out to 48 hours, which is what we did use in the Three Mile Island incident, we're not interested in the situation over the first hour or the second hour, but we are interested in how far these radio-isotopes are going to be transported, and where they're going to be transported. This is a long way down the trajectory. So these I see as two different problems; they're the same problem, but they have two different aspects. Certainly you would have to have dispersion modelling to deal with the immediate situation and for immediate evacuation, but the other problem, which relates to further down the way; out 10 hours, 12 hours, 24 hours down the line, is something that we have to use the CMC capability for.

R.V. PORTELLI: I'd like to interject with something here. I received a call last week from someone from the National Energy Board who was responsible for writing the revised guidelines for the nuclear power industry in Canada, and one of the things he pointed out is in setting up the meteorological scenarios which they include in the guidelines, they have no expert meteorological input. I suggest that everyone here, and people from the regions in particular, when making contact with such organizations, instill with them the idea that they do need this expert information in a formal context, not an informal telephone call. They are adopting U.S. meteorological scenarios, and are not knowledgeable as to whether or not they're applicable for Canada, and when I pursued it further with him, he indicated that the power utilities themselves, who are putting together the nuclear installations, are not very concerned with setting up on-site meteorological programs, because their response is, "If we have an accident, all we need to know is the direction and speed of the wind and we can answer the rest." So they don't feel there is that need for identifying the

on-site meteorological characteristics, and setting up such routine capability or emergency responses. Now I'm sort of countering my own philosophy in the response that industry has, and at the same time you listen to the activists such as Jane Fonda on the recent U.S. concerns, that you can't trust power utility executives because of their profit making orientation. I sort of pose with you this problem, that we first of all have to get ourselves into a forum where we're providing this kind of expert information to people who are setting these guidelines, and that we should resolve these problems early before they are already written into NEB or AECB regulations.

G. DESAUTELS: I'd like to know in view of the fact that there is a law on contaminants which we have to deal with on a regional basis, when we assist at those regional meetings, there are also people from EMS and EPS present there, and up to now there were also people present from DFO. Now, the thing we find is that when we're talking about substances like Myrex, or PCB or HCB or any kind of similar substance, we find that the people from EMS will look after the fish and the water, and they'll come up with a project and study to really study the presence of thos contaminants in the environment. Now, the same thing will be done by EPS also, which will go over to do the inventory of the sources, etc. AES is asked what we really do to look into the atmosphere and see for example, the presence of those substances in the atmosphere. We're not talking now about a real case study about the emission of one stack or a set of stacks of one particular substance, they are talking really about the background presence of those substances and here and there this question is asked again, and we always have to answer the same thing, that we don't have that kind of money to support those kinds of programs. I'm just wondering; this is part of AES mandate, and when we ask the question we get the reply that there is not enough money, so I'm wondering if we are in a closed circuit here. When will the circuit break, or will the situation always prevail where AES is not doing it's job?

A.D. CHRISTIE: I'm afraid I can't answer for Senior Management, but I think really that we all appreciate that there is a limitation on the resources available. Now when we're dealing with pesticides or contaminants or anything else, we're talking in general, even to measure in the air, we're talking about high technology, instrumentation that you don't buy off the shelf for a few dollars. We are in the process of trying to have developed for us an instrument for measuring mercury at the present time - one of the things you get questioned about, and one of the things you've heard mentioned from one of the regions this afternoon. The contract for development of an instrument suitable for measuring mercury in the atmosphere is something of the order of about $400,000 at the present time. Now that's part of a program. You can design models that will try and make a prediction of pathways in the atmosphere, but without measurement you have no way of validating that model at all. So it is a valid question. The problem in the aquatic environment isn't quite so bad, because it is easier to measure the concentrations that you get in the aquatic environment to measuring in the atmospheric environment. So that's one valid problem. The other one simply is resources. It is difficult to have the money for the instrumentation and to design the modelling.

QUESTION 3 (J.W.S. Young):
What new areas in air quality do you feel will become important or topical in the near future, and what additional technical support do you need for these areas?

R.E. MUNN: One is the carbon dioxide problem and climate change, and another one is the acid rain problem, but there are other kinds of studies and Al has referred to them in a general way on his following pollutant pathways from source to receptor. For example, the Ontario Hydro has called for tenders, and one came to the University of Toronto to do a complete study. They want to increase their export of power to the United States by 10%, and in order to do that they have to go to the National Energy Board with an impact assessment which will indicate the effects this extra 10% (the incremental effects, not the present effects) of export power will have on the people in Ontario. So, that's a nice problem, and you have to bring in everyone from the epidemiologist, people like Marlene Phillips (Biologist) and the transport people. It's not an easy question, and in fact the University of Toronto decided not to bid on this tender because they didn't want to sit on that side of the fence, they thought it might not be appropriate. In fact there was a letter that went to the National Energy Board suggesting that it would be a useful thing for somebody to do, but they thought it should be funded through the National Energy Board, so I don't know what they'll think of that answer. Those are some of my thoughts on this question.

QUESTION 4 (J.W.S. Young):
Specifically with respect to training, what are the air quality training needs within AES and this includes all of AES, and for users of air quality data, and how best can we meet these needs? Suggestions include: through workshops, courses. And should these be open to the public and industry? What about training visits and other areas that were mentioned this morning; particularly more technology transfer, and having a national program of courses for example.

S. NIKLEVA: The air quality needs within the region, or training needs? I think that before we can answer that question, we have to look to find out what the role of the region will be with regard to air quality, and I think from this, the certain level of expertise required for that role, whatever it is. I might just add that at the present time it seems to be SSD's policy that the role of SSD will be defined by the regional director, so that in this case, the role can vary quite a bit between regions, and this might give some problems as far as getting a training program that's going to be applicable to each region.

H. FRASER: I think perhaps Steve (Nikleva) that one of the answers to your question is something which came up a couple of times today. I mentioned that I think we should have regional workshops on air quality. Now there's another great advantage in this. As a Scientific Services manager, I'm in a rather difficult position if I try and choose meteorologists on whatever basis, out of the operational system, to be trained as air pollution meteorologists. It is a very simple process; who are you going to extend the favour to? Who are you going to open the door slightly for? You can get yourself into difficulty in the regional office doing things like that, but if we get that course in the region we can give it to quite a few meteorologists, even it it's a small course, and is open for them to come to. You see, we can't send everybody down here on courses. We can only send one or two, but if we get this into the region, then anyone that's available can come. So I think that's a good point. I'll go on to be very specific. I was thinking of answering Phil Aber (Training Branch) on this one. If you wanted to be very specific about what I would like to see as training for regional meteorologists I would say:

Session 2, Tuesday morning backed up with Session 4, which I think is Wednesday (from this workshop); those are the top priorities right there for the regions. Now we come to a very interesting national meeting like this, and we receive all sorts of interesting material to the Chiefs of Scientific Services and to the people who work in air quality, but the real need for increasing the expertise in the regions has not much to do with policy or jurisdictions or long-range projections, its people with a technical expertise in air pollution meteorology. So those two sessions I think, would satisfy our immediate needs perhaps. I would like to suggest that this idea of training into the regions in a workshop fashion be pressed.

A.D. CHRISTIE: I think there is only one problem with this, and again it comes down to resources; how much it costs to send out a group into the regions to give a course, but this can be got over to some extent by using videotapes. Many of the courses that Ron (Portelli) has organized already for EPS have been put on videotape, and I see no objections to having someone like Ron, with the knowledge of the whole background of the course, accompanying this, and being there to give that added tutorial that is necessary; that first-hand information, the interface. But I see that only as part of an overall system. The final thing that is down here, the 6 month assignments to headquarters, or to Downsview, I see as something that could contribute in a very valuable way, because not only does it expose people to the techniques that are in principle available, but it lets them get a hands-on experience, and more than that, it lets them find out who the individual experts are, and there are people with specialized information. It may very well be that on dispersion problems there is a model that can be used, but if it's a question to do with a specific part of the overall environmental assessment, things like deposition, and they're here, they know that they can go to Doug (Whelpdale) or Len Barrie. If it's someone who needs to know something about plume rise, they know to go to Fouad Fanaki. They get that first-hand knowledge, which means that they can go to the source shen they have a problem in their own area. Now I don't want to imply that when they are in the region that everybody in the regional office should be phoning these people directly at the drop of a hat, but I think we are all mature enough to know that this won't happen. It's a question of the knowledge. I think the experience of working with our team here in Downsview, gives people a first-hand hands-on knowledge of what's available, and what we can't do. It allows them also to help pose the questions that can give us the next stage in the development work. What are the kind of questions that you have that you know can't be answered in the region, that you have a fair idea we don't have something on line for here, but you think we have the capability and capacity to deal with it.

R. LAWFORD: In connection with training needs, I think I'd echo what Hugh (Fraser) has said as far as the definition of needs. I suggest basic air quality meteorology should be given to people who want to get into scientific services. Dispersion, regional and long-range transport models, microscale meteorology and the role of topography in the dispersion of pollutants, that would be good for an inhouse course for meteorologists. As far as going outside to educate the public or other users, I suggest that rather than do this in isolation that we should put together a package with other services in the Department of the Environment involving the total package of environmental assessment. There might be a module on water quality assessment, etc., so that consultants could send a fairly significant group of people to participate in a workshop of this nature. I guess their people would be spread

reasonably thin on dealing with problems; they have to jump from one problem to quite a different problem, from review to review. The Ontario region has had workshops for urban planners, wildlife managers, and lately, recreation and tourism, and we have had between 50 and 100 people who up at each of these workshops. That's just from the Province of Ontario, and we simply send out a circular describing what we are about, what we intended to during the day, and we got that sort of response. So, if a package like this was put together on a regional level, I suspect that we'd get a similar response. It would be good to have both regional and air quality directorate input into such a program.

J.W.S. YOUNG: From the point of view of training, sort of a peripheral view, do you see it being useful to have a federal package or an AES package of, talking about specifically air pollution models, available that should be recommended to industry, or do you think it's worthwhile transferring to them, say through a training course, rather than letting them use anything they want?

R. LAWFORD: I think it would be good if we had a package available to outline what types of models were available, but perhaps to maintain some continuity in the types of models they apply, we should perhaps encourage them to come to us and discuss their specific problems, and then on the basis of guidance given, they could go and apply a certain model; perhaps we could supply them with a model, perhaps the consultant could supply them with a model, such as the case with the urban runoff model that IWD has developed.

G. DESAUTELS: I think that when you are considering the problem of training the personnel in the regions, you have also the problem of training the personnel at headquarters. I think that you need to let the personnel at headquarters realize that there are personnel in the regions who may support the project, or who are there really, and are anxious to learn what is going on. I think that a good deal of communication with the regional SSD on every matter going on in the region, which is implying the headquarters is the basis of a good communication and a good training. After that, I think that ARQD should keep aware that whenever possible, it should try to set up projects with regional participation, so that personnel in the region could gain expertise, it could gain closer contact with the personnel in ARQD.

R.V. PORTELLI: With regard to the comments that Hugh and Rick made about air pollution meteorology training, to date we've done this, but only in response to EPS requests as part of their training program. We put together the last one in December, and now we're going to have one following this week, right here. It will be the first one we've given here. Now, historically, these have been of the order of 30 - 35 individuals once every year or year and a half. We waited two years this last time, and we had a demand of 60 for December. We don't advertise this, EPS does. For next week's course we have about 60. Most of it was run off from the last one, and the majority of these individuals are coming from the Ministry of the Environment of Ontario. I'd say 35 - 40 of 60 people. We are in the process of making this an AES program, or an AES training course. I think if the regional people identified needs in specific terms, ongoing programs, maybe annually or semi-annually, could be set up to do this sort of thing.

C.D. HOLTZ: Training Branch and in particular, Professional Development Unit, is always prepared to put on courses, depending on what the needs of the regions are. We've been thinking about an air quality program for some time. We've been waiting now for the regions to specifically put in their request for this kind of program. If we don't have the expertise in Training Branch, then we will solicit experts from other organizations; we've done that in the past, and we plan to do it again in the future in order to put programs requested by the regional people. You were mentioning that we should put on workshops specifically for a region; we're doing this all the time. This is what we're calling our Type B Workshops, where we design a program specifically for a particular office. We will also design courses, we will bring people here, into headquarters, where we will teach them air quality in general but if you want a specific for your office, we'll design a Type B Workshop for that kind of program. We will coordinate our activities with the regional office so that we will then train the people within the regional office to be experts so that when we leave, then the experts remain there.

G.A. McBEAN: Well, before Cliff (Holtz) spoke and told us that Training Branch was willing and able to do everything, I was going to make the comment that I didn't think it was appropriate that AES do all this training. One of the recent decisions, I thought, of AES regarding meteorology training was that the university should do more of this to a more advanced stage, and there would be some final, sort of operations orientated courses before the forecaster goes running out into the field office. I am wondering why we cannot take more advantage of the courses that in some places are offered in universities, or encourage universities to offer more courses in air pollution meteorology as part of meteorology programs. As some of you know, there is a course in micrometeorology, which occasionally mentions air pollution at the University of Toronto, and Ted Munn is there giving courses I'm sure. There are courses that most Canadian universities offer if you look for them. Now they may not give you the applications package that is needed, but I think these could go a fair way towards meeting some of the requirements in various areas.

H. FRASER: Gordon, if you think there are courses available in Canadian universities you've come from a different part of Canada than I do. There are some courses in the University of Manitoba in Geography, the chance to do climatology; there is one half course on the application of meteorology to agriculture, in which I participate, and there is not a solitary air pollution meteorologist that I know of, in Saskatchewan and Manitoba inside or outside the universities. I don't think we're saying that AES should be doing a lot of training, we're just saying that we have people who need training, and have nowhere else to get it that we know of. So I'm beginning to think that maybe we could get it from EPS.

G.A. McBEAN: You may be correct, there are lots of places in Canada without this kind of expertise, but I think perhaps we as the meteorological community should be pushing the universities to have such things, and we should be pushing in view of this recent change in training that there be some air pollution meteorology taught as sort of compulsary within MSc courses for our new forecasters or whichever people we bring in to the AES.

QUESTION 5 (J.W.S. Young):
This is really aimed at the regions looking for input. We're just wondering what you think should be the breakdown at headquarters between what has been referred to today as air quality applications, and perhaps the more pure research function.

R. LAWFORD: Just a point of clarification; when you say air quality research, are you taking into consideration boundary-layer research, dispersion research, air chemistry?

J.W.S. YOUNG: Everything.

R. LAWFORD: Okay, and the present breakdown is what? What would be the ratio between applications and research at present?

J.W.S. YOUNG: I would say that applications has not been stressed in the past, but is gaining more prominence at the moment.

R. LAWFORD: I would say from the point of view of transfer of technology that another 5% should be added, a growth to 10%, but I couldn't see it going beyond 10%. I think basically, the air quality research directorate is looked to for basic research, and basic information on problems, and that role shouldn't be eroded by making it a great applications unit.

S. NIKLEVA: I think we should also recognize that guidance in applications should be the role of ARQD, too, and a lot of this discussion on packaged models that could be supplied to the region; I don't think that packaged models should be what we should be looking at. The province has packages themselves, and so does EPS and I think that a better effort would be if we could get with the provinces and discuss the weaknesses in the models that they're applying to the meteorology of the situation. So I think we could make a positive contribution in that regard and whether we should get guidance from ARQD or from some area in ARD, I think that we should and that we haven't been doing so.

A.D. CHRISTIE: I think the breakdown in the amount of effort that is put in air quality research branch into research as opposed to application is a little bit artificial. It seems to me that there are really three scales of problems in air quality. There's the global problem, which really doesn't have very much impact on the regions apart from the part that they have in making the observations, the regional part of the observational network. This I see as a unique part of air quality research branch work, and should continue. In the medium scale, the transboundary pollution is obviously something which requires developmental skills and is to a large extent basic in research. That I would see continuing, and that is a kind of problem which is an extemely important problem that should be supported and should be continued. Now, the dispersion problem, the applications for dispersion are definitely the ones that are felt in the regions. This I see as a requirement, to develop a system which can be used in the regions, and to the extent that we have one or two packages that are being developed here or developed elsewhere and applied here, I see that there is a place for discussion between the regions and ourselves in the planning level and in the implementation level. I think that that is one area that does need to be expanded.

R.E. MUNN: I'm a little bit surprised that nowhere today have we heard anything about the role of the private consultants and where they fit in as compared to the applications at headquarters and what the regions will do. I'm not a consultant, so I've got no personal interest in this, but there are some very good ones around the country now, and perhaps at some stage you should, maybe you are interfacing with them in trying to decide what the guidelines should be.

A.D. CHRISTIE: I would say, again, that the problem here is one of consistency. If you use one consultant, then either you make his technique a generally accepted technique, you know that the limitations of that technique are, and you take these into account when you make any environmental impact assessment. So this really means that you've got to take his package apart and really get to understand what it is that he's providing, and in many cases they have done valuable work, that we could take advantage of him that way. There are obvious places where the consultant comes in; in the preparation of an environmental impact statement in the first place. There shouldn't be the requirement for AES to get involved. We need to get involved in the review process, but in the preparation of the environmental impact statement, I see much greater scope for consultants in that area. There are roles for both of us as far as I see.

J.W.S. YOUNG: In summary, I heard a number of comments about surveying user needs, and I think we definitely have to do that. A comment was made that we don't market our products properly, and I think that's a valid criticism, and that perhaps headquarters doesn't have a very clear regional image, and perhaps we need a better one. I think clarification was also asked for on AES policies with regard to environmental emergency responses, and also to clarify what the role of the region is in air quality. I hope that this workshop will do some of that. From the point of view of applications, there appears to be a large need for technology transfer, and specifically regional workshops are required.

THEORY AND APPLICATION OF GAUSSIAN DISPERSION FORMULATIONS

C.S. MATTHIAS
Air Quality Assessment Section

CONDITIONS FOR GAUSSIAN APPLICATION

If a finite amount of pollutant is injected into the atmosphere, the cloud will grow in all directions. If the atmospheric properties are stationary (unchanging in time) and homogeneous (unchanging along any space coordinate), then the distribution of pollutants within the cloud is Gaussian (Lamb, 1978), with the concentration χ peaking in the center and dropping off with distance according to the formula

$$\chi = \frac{Q_\tau}{(2\pi)^{3/2}\sigma_x(t)\sigma_y(t)\sigma_z(t)} \exp-\left(\frac{(x-Ut)^2}{2\sigma_x^2}+\frac{y^2}{2\sigma_y^2}\right) \times\left\{\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right\} \quad (1)$$

where Q_τ is the total mass released, σ is the standard deviation of the concentration distribution, U is the wind velocity directed along the x axis, and t is the time elapsed since the release at a point (o, o, H). This expression assumes that material is reflected at the ground but diffuses upward without limit (Turner, 1970). The assumption of stationarity is reasonable over a period of one or two hours except during a frontal passage or during rapid convective breakup of the morning inversion. The quasi-stationary atmosphere can be considered horizontally homogeneous provided that the terrain is uniform and moderately flat. The atmosphere is much less homogeneous in the vertical direction, causing some deviation from Gaussianity. The deviation, however, is not sufficient to detract from the usefulness of Gaussian formulae.

POINT SOURCE MODELS

2a. Puffs

The puff model (Eq. 1) describes the concentration field due to an instantaneous release of total mass Q_τ. The pollutant cloud drifts with the wind and expands with time. The impact on a stationary receptor is not so much a function of concentration (which changes continually) as of the time integral of the concentration, or dosage D. Because of the exponential term, the puff will make a significant contribution to the receptor only when it is nearby, ie., when the travel time t is of the order $t = (x \pm \sqrt{2}\,\sigma_x) / U$. If the puff dimensions remain constant during this time, then using Eq. (1), the integrated effect of the puff as it passes by is given by $D = \int_0^\infty \chi dt$ or

$$D = \frac{Q_\tau}{2\Pi U \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \quad (2)$$

where the σ_i are evaluated at $t = x/U$.

The condition imposed on the σ_i during the time period $\Delta t \approx \sigma_x / U$ is satisfied provided that $d\sigma_x/\sigma_x << 1$. Since the growth rate of σ_x is not likely to exceed the horizontal turbulent velocity u, then $\Delta \sigma_x \simeq u \Delta t \simeq u \sigma_x / U$. The condition on σ_x then is satisfied provided that u/U or q/U << 1 where $q^2 = u^2 + v^2 + w^2$, the sum of the velocity variances in the x, y, z directions.

During the integration leading to Eq. (2), an error function $\mathrm{erf}(x/\sqrt{2}\,\sigma_x)$ arises. But the ratio x/σ_x will equal or exceed U/u which is sufficiently larger than 1 so as to make the error function equal to unity. The error function is defined as

$$\mathrm{erf}(\xi) = \frac{2}{\sqrt{\Pi}} \int_0^\xi \exp(-t^2)\,dt$$

Normally, pollutants are restricted in their upward diffusion by a stable layer aloft at a height L. If we can assume that no material passes through this "lid", then eventually the pollutant is uniformly mixed in the vertical direction within the depth L. If we redistribute the mass as described by Eq.'s (1) and (2) into a depth L, we get

$$\chi = \frac{Q_\tau}{2\Pi\,\sigma_x \sigma_y L} \exp - \left(\frac{(x-Ut)^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2}\right) \quad (3)$$

$$D = \frac{Q_\tau}{(2\Pi)^{\frac{1}{2}} \sigma_y L U} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \qquad (4)$$

Following the convention in the Workbook of Atmospheric Dispersion Estimates by Turner (1970), the unlimited mixing equations (1) and (2) may be used up to a distance x_L from the source, and the limited mixing equations (3) and (4) beyond a distance $2x_L$ where x_L is given implicitly by the expression $\sigma_z(x_L) = .47\ L$. An interpolation scheme is used for intermediate distances.

2b. Plumes

A source which emits continuously generates a plume which can be considered to be made up of a succession of puffs. If a receptor is located at $\underline{r}$ (x, y, z), each puff component contributes to the concentration at $\underline{r}$. The exponential term in Eq. (1) assures that only those puffs near the receptor will make a significant contribution. Using the same argument as in Section 2a, we can integrate the effect of all the puffs as described by Eq. (1). Keeping the sigmas (σ_i) constant and evaluating them at x, replacing Q_τ by Qdt where Q is the emission rate in mass units per second, and integrating Eq. (1) for travel times from zero to infinity, the plume concentration becomes

$$\chi = \frac{Q}{2\Pi U \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \qquad (5)$$

The same boundary conditions apply to this equation as to Eq. (1), ie., perfect reflection at the ground and unlimited mixing upwards. If vertical diffusion is limited by an elevated stable layer, then far downstream the concentration distribution becomes uniform in the vertical and is described by

$$\chi = \frac{Q}{(2\Pi)^{\frac{1}{2}} U \sigma_y L} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \qquad (6)$$

Eq. (5) and Eq. (6) apply for $x < x_L$ and $x > 2x_L$ respectively, as described in Section 2a.

A more accurate description of the plume concentration within a capped mixing layer considers multiple reflections from

the upper and lower boundaries. For a receptor at ground level, the concentration is given by (Turner, 1970)

$$\chi(x,y,o) = \frac{Q}{\Pi U \sigma_y \sigma_z} \exp\left\{-\frac{y^2}{2\sigma_y^2}\right\} \sum_{n=-\infty}^{\infty} \exp\left\{-\frac{(H+2nL)^2}{2\sigma_z^2}\right\} \qquad (7)$$

Close to the source (for $x < x_L$), only the first few terms contribute to the expression. An example of the importance of successive terms is given in Fig. 1. The figures display non-dimensional concentrations using Eq.'s (6) and (7) as a function of non-dimensional downwind distance expressed as $\xi = \sigma_z/L$ (assume $\sigma_y = \sigma_z$). The exact solution as given by Eq. (7) is approximated by a summation from -5 to +5. This is seen to fail for $\xi > 4$ since it begins to fall short of the limited mixing (LM) solution Eq. (6) which is exact for $\xi >> 1$ (recall that x_L occurs at $\xi = .47$). The n values in each curve indicate the terms used in Eq. (7). The expression using n = o alone corresponds to Eq. (5).

Using Eq. (7) for small ξ, we are interested in the minimum number of terms which bring this expression close enough to the exact solution. The only case for which the n = o term is insufficient is illustrated in Fig. 1C for plume elevations close to the mixing height. In this case, the n = o and n = -1 terms together approximate the exact solution very well. If Eq. (7) is used for $\xi < 1$, and Eq. (6) for $\xi > 1$, then for H/L = 1, and $\xi = 1$, we have

	n = o	n = o,-1	n = o,-1,+1	
$\frac{\chi}{\chi_{exact}}$	.49	.98	.99	$\frac{\chi_{LM}}{\chi_{exact}} = 1.01$

The location x_{max} and magnitude χ_{max} of the maximum ground level concentration can be deduced from Eq. (5). Putting y = z = o, assuming $\sigma_z/\sigma_y = b$ = constant, and differentiating with respect to σ_z, we find

$$\chi_{max} = \frac{2\,Q\,\sigma_z}{\Pi e H^2 U^2 \sigma_y} \qquad (e = 2.72) \qquad (8)$$

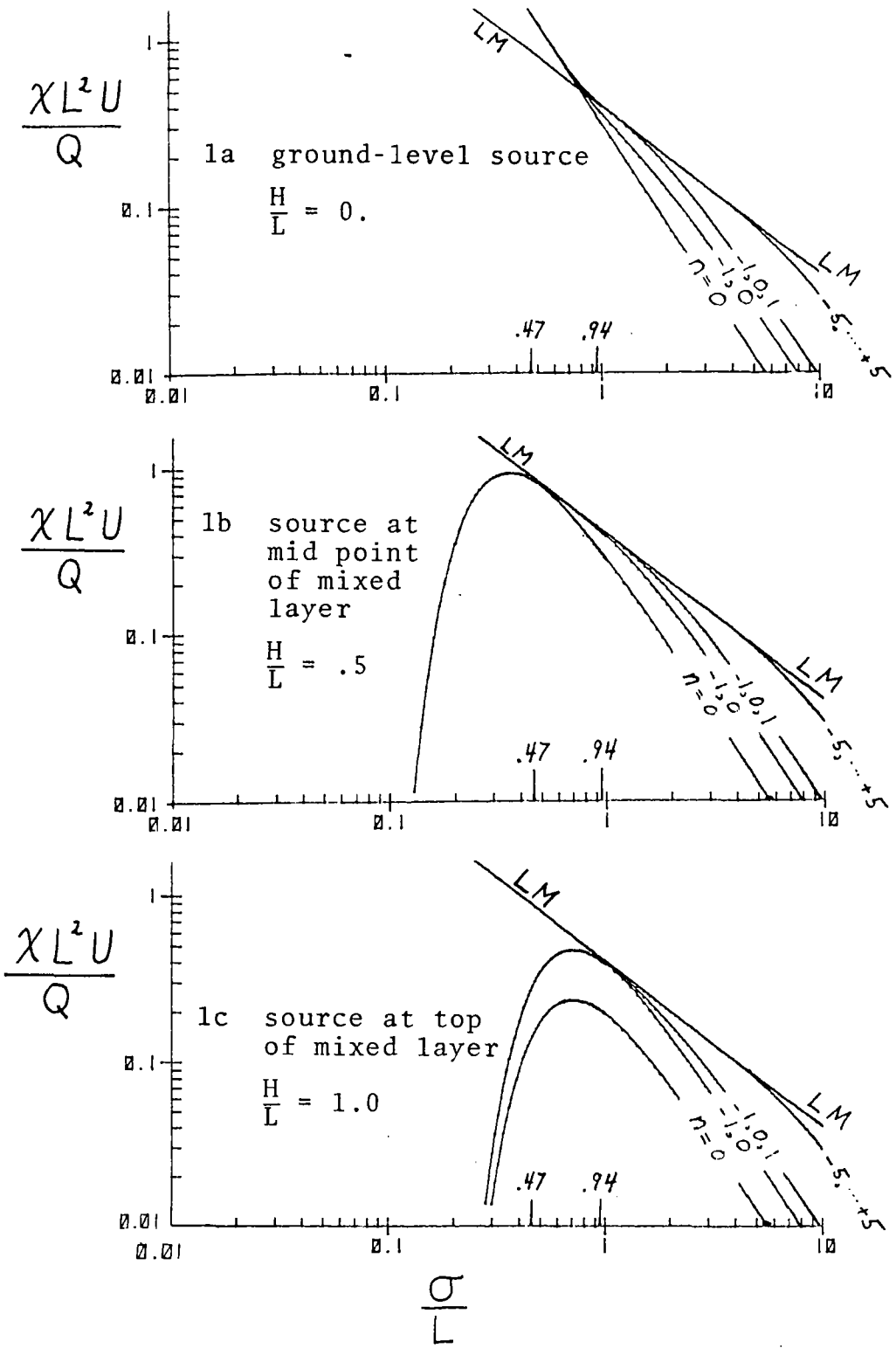


Fig. 1. Curves of concentration vs. distance plotted non-dimensionally, using Eq.'s (6) and (7), for sources at 3 different heights H. LM refers to the limited mixing equation (6).

$$\sigma_z (x_{max}) = \frac{H}{\sqrt{2}} \tag{9}$$

If the plume height H is close to the inversion height L, then both the n = o and n = 1 terms are important in Eq. (7), leading to a doubling of the concentration field everywhere, including χ_{max}. There is very little published data available to compare with either Eq. (8) or Eq. (9) but it seems that the concentration χ_{max} is better predicted than the location x_{max}, (Gifford, 1975).

Recent water tank results provide an interesting comparison to Gaussian model results (Willis and Deardorff, 1978). The conditions of the experiment correspond to sunny convective conditions with low to moderate wind speeds, whose Pasquill-Gifford (PG) stability category is given by A or B. For a non-buoyant source located at a height H = .26 L, Fig. 2 shows the isopleths of the crosswind integrated concentration to be very non-Gaussian in appearance. The figure is a composite of seven experiments, each corresponding to a sampling duration of 20-30 minutes. The plume centerline descends to ground level, remains there for some distance, and rises again. The explanation in atmospheric terms is as follows: Atmospheric turbulence is comprised of several decades of length scales. The eddies which are of size L form updrafts and downdrafts which move the plume bodily. The updrafts are slightly unstable and disperse the plume whereas the downdrafts are slightly stable and tend to maintain plume integrity. When plume concentrations are averaged over a long time period, they net effect is to transport the plume downwards.

Beyond the point of maximum concentration, the plume centerline rises. The long-lived large scale eddies are more efficient at lifting the surface material than is the process of pure diffusion. Further downstream, the concentration becomes fairly uniform in the vertical direction.

As hopeless as a Gaussian fit to Fig. 2 may be, a consideration of surface concentrations alone is much more encouraging. Using Eq. (5) with y = z = o, and experimentally measured values of σ_y and σ_z, the authors find a surprisingly good comparison of the Gaussian prediction with the observed measurements(Fig. 3).

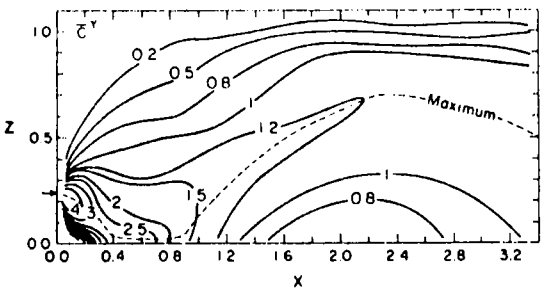


Fig. 2 Smoothed contours of dimensionless cross-wind integrated concentration as a function of height and downstream distance.

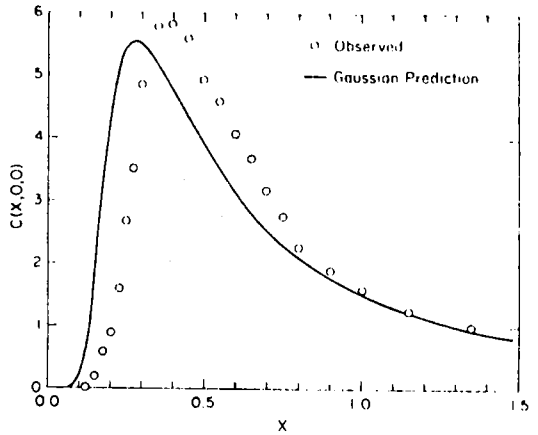


Fig. 3 Observed values and Gaussian predicted values of ground-level, centerline dimensionless concentration. To obtain Gaussian prediction, observed values of σ_Y and σ_Z were used.

This offers the hope that traditional Gaussian formulae can be applied to estimate the ground level concentration of pollutants from a tall stack, provided that suitable values of σ_y and σ_z are known. The results of an earlier study (Deardorff and Willis, 1975) and of a later but purely numerical study (Lamb, 1979) have been synthesized into Gaussian formulae. The sigmas are expressed in terms of convective boundary layer variables, ie., surface heat flux and mixed layer height.

LINE SOURCE MODELS

A line source can be considered to be a series of point sources. The concentration field downwind of the line source can be found by adding all the point source contributions as given by Eq. (5). This must be done numerically for general configurations but can be done analytically for straight line sources. The concentration field from the line source is more complex than that of a point source because of the need to consider the wind angle relative to the line, and the finite length of the line. To reduce analytical complications, the following development will use only the n = o term of the point source equation (7).

3a. Wind Perpendicular to Finite Line Source

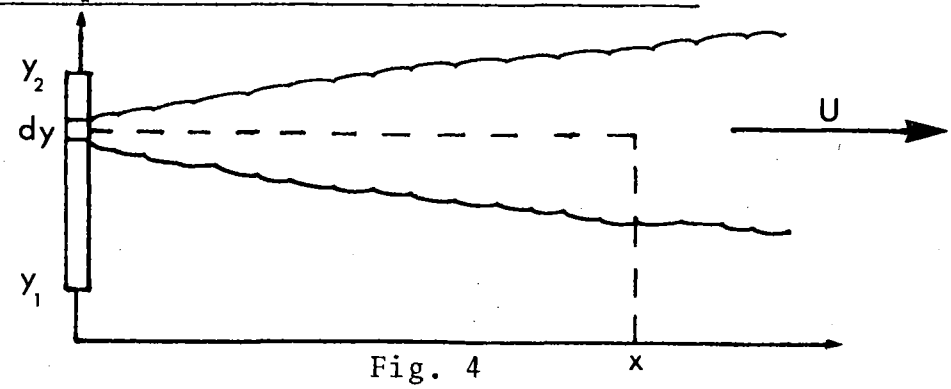


Fig. 4

$$d\chi_{\perp}(x,o,o) = \frac{Q_\ell dy}{\pi U \sigma_y(x)\sigma_z(x)} \exp\left(-\frac{1}{2}\frac{y^2}{\sigma_y^2(x)}\right) \tag{10}$$

$$\chi_{\perp}(x,o,o) = \frac{Q_\ell}{(2\pi)^{\frac{1}{2}} U\sigma_z(x)} \left[\mathrm{erf}\left(\frac{y_2}{\sqrt{2}\sigma_y(x)}\right) - \mathrm{erf}\left(\frac{y_1}{\sqrt{2}\sigma_y(x)}\right)\right] \tag{11}$$

Consider the line source to be horizontal, lying along the y axis and extending from y_1 to y_2. The receptor is located at (x,o,o). Knowing the source strength per unit length Q_ℓ, the concentration at the receptor due to the element dy at y is given by $d\chi_{\perp}$, above, using Eq. (5). Since the sigmas remain constant for any y, the integration over all the elemental sources is straight forward. The concentration is expressed in terms of the error function erf (ξ) for which tables are available.

The concentration at a more arbitrarily located receptor (x,o,z) is readily found since the z-dependent term in Eq. (5) does not enter into the integration.

$$\chi_{\perp}(x,o,z) = \chi_{\perp}(x,o,o) \exp\left(-\frac{z^2}{2\sigma_z^2(x)}\right) \tag{12}$$

The concentration due to an infinite line source is found by allowing y_1 and y_2 to approach $-\infty$ and $+\infty$ respectively. Eq. (11) becomes

$$\chi_{\perp}(x,o,o) = \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \frac{Q_\ell}{U\sigma_z(x)} \tag{13}$$

3b. Wind Parallel to Finite Line Source

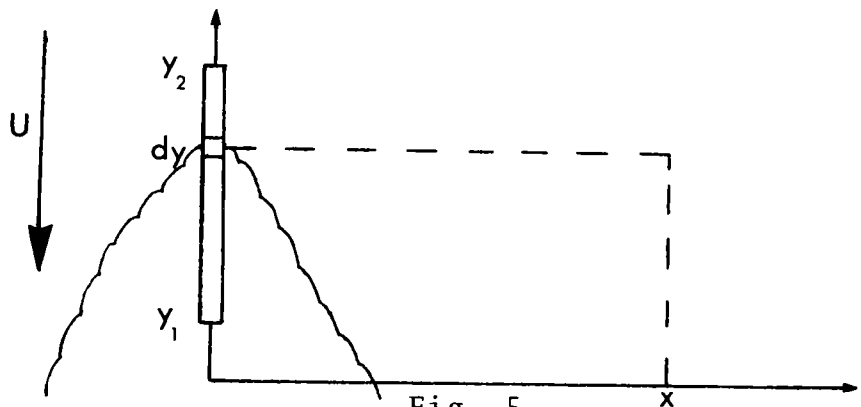


Fig. 5

$$d\chi_{11}(x,o,o) = \frac{Q_\ell dy}{\Pi U \sigma_x(y)\sigma_z(y)} \exp\left(-\frac{X^2}{2\sigma_x{}^2(y)}\right) \tag{14}$$

$$\chi_{11}(x,o,o) = \frac{Q_\ell}{(2\Pi)^{\frac{1}{2}} U\sigma_z(x)}\left\{\text{erf}\left(\frac{X}{\sqrt{2}\sigma_x(y_1)}\right) - \text{erf}\left(\frac{X}{\sqrt{2}\sigma_x(y_2)}\right)\right\} \tag{15}$$

The intermediate steps between Eq.'s (14) and (15) require the assumptions

$$\frac{\sigma_z}{\sigma_x} = b = \text{constant}; \quad \sigma_x(y) = \frac{u\ y}{U} \tag{16}$$

It is assumed that the dispersion width σ_x varies linearly with distance (or time of travel). This is consistent with both theory and experiments for short downstream distances y. The functional dependence of $\sigma_x(y)$ at large y is not important in the above development since the elemental contribution is small.

The concentration at an arbitrary height z can be evaluated by retaining the z terms in Eq. (5) to yield the more general expression.

$$\chi_{11}(x,o,z) = \frac{Q_\ell}{(2\Pi)^{\frac{1}{2}} U\sigma_z(r)}\left\{\text{erf}\left(\frac{r}{\sqrt{2}\sigma_x(y_1)}\right) - \text{erf}\left(\frac{r}{\sqrt{2}\sigma_x(y_2)}\right)\right\} \tag{17}$$

where $r^2 = x^2 + \frac{z^2}{b^2}$

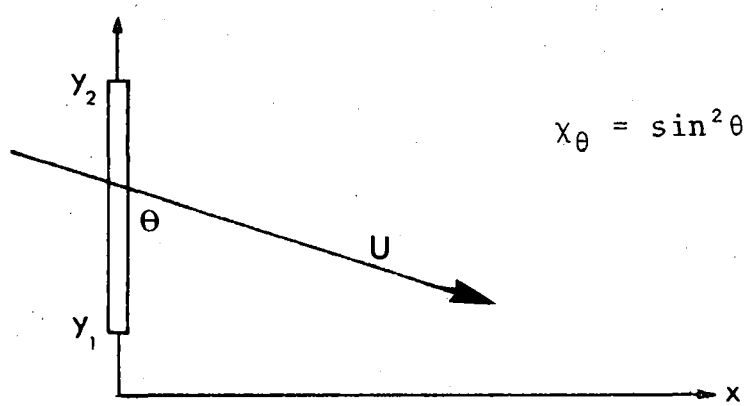
This is intuitively deducible from Eq. (15) for the special isotropic case of b = 1 since the distance x appearing in the variable

$\sigma_z(x)$ is merely the radial distance from the source. If the receptor may be located anywhere in the x-z plane, the radial distance becomes $r = (x^2 + z^2)^{\frac{1}{2}}$.

For an infinitely long line source, only the upwind portion of the source in Fig. 5 will contribute to the receptor at (x,o,z). Evaluating Eq. (17) for $y_1 = o$ and $y_2 = \infty$ gives

$$\chi_{11}(x,o,z) = \frac{Q_\ell}{(2\Pi)^{\frac{1}{2}} U \sigma_z(r)} \tag{18}$$

3c. Arbitrary Wind Direction Relative to Line Source



$$\chi_\theta = \sin^2\theta \; \chi_\perp + \cos^2\theta \; \chi_{11} \tag{19}$$

Fig. 6

Ground level concentrations due to parallel and perpendicular winds relative to infinite line sources differ only by a factor of 2 (Eq. (13) and Eq. (18)). Since the concentration is expected to vary monotonically as the wind changes from parallel to perpendicular, a simple interpolation scheme joining the general expressions (Eq.'s (12) and (17)) should be satisfactory. This is given by Eq. (19) above.

3d. A Line Source Remote from a Receptor

As the receptor is withdrawn further from the finite line source as pictured in Fig.'s 4 or 5, the difference $\mathrm{erf}(\xi_2) - \mathrm{erf}(\xi_1)$ in Eq.'s (11) and (15) becomes much smaller than each of the erf terms themselves and accuracy suffers. This situation can happen in two ways: by increasing x or by increasing y_1 and y_2. As x increases indefinitely, $\xi << 1$ in Eq. (11) and $\xi >> 1$ in Eq. (15). Conversely as y_1, y_2 increase indefinitely, $\xi >> 1$ in Eq. (11) and $\xi << 1$ in Eq. (15). Intuitively, one expects a

remote finite line source to resemble a point source. By examining asymptotic expressions for $\mathrm{erf}(\xi_2) - \mathrm{erf}(\xi_1)$, we can see at what distance and with what error this approximation can be made. The argument will always be positive in these asymptotic cases, as are $\mathrm{erf}(\xi_2) - \mathrm{erf}(\xi_1)$ and $\xi_2 - \xi_1$.

For ξ_1, $\xi_2 >> 1$, one can show that

$$\mathrm{erf}(\xi_2) - \mathrm{erf}(\xi_1) \simeq \frac{2\Delta\xi}{\sqrt{\pi}} \exp\left\{-\xi_1^2\right\}\left\{1 - \frac{\Delta\xi}{\xi_1}\right\} \tag{20}$$

where $\Delta\xi = \xi_2 - \xi_1$ and $\Delta\xi << \xi_1, \xi_2$. Substitution of the dominant term in Eq. (20) into the line source equations reduces them to point source form. The second term in Eq. (20) represents the correction to the point source formula to make it equivalent to a line source formula when $\Delta\xi/\xi_1$ is small. Using Eq.'s (11), (15) and (20) we can see that

$$\frac{\chi_{exact} - \chi_{approx}}{\chi_{exact}} \simeq -\frac{\Delta\xi}{\xi_1} = -\frac{(y_2 - y_1)}{y_1} \tag{20a}$$

from which it is evident that the approximate concentration χ_{approx} as given by the point source formula Eq. (5) is slightly larger than the exact concentration as given by Eq.'s (11) and (15). If we use the point source equation to replace the finite line source equation when ξ is large, we will overpredict slightly with the relative error given by Eq. (20a). For example, to maintain a 10% accuracy in concentration calculations, the ratio of segment length to distance from receptor y_1 should be less than 0.1. Of course this assumes that there are no other sources of error in these equations. Other errors will be discussed briefly in Section 6.

For ξ_1, $\xi_2 << 1$, one can show that

$$\mathrm{erf}(\xi_2) - \mathrm{erf}(\xi_1) \simeq \frac{2\Delta\xi}{\sqrt{\pi}}\left\{1 - \xi_1^2 - \xi_1\Delta\xi\right\} \tag{21}$$

When the first two terms of this expression are substituted into Eq.'s (11) and (15), the result is identical to the expansion of the point source equation Eq. (5) for small exponential argument. The third term in Eq. (21) is the correction to the point source

formula to make it equivalent to a finite line source formula. The relative error in using the point source formula is far less for $\xi << 1$ than for $\xi >> 1$ and is given by

$$\frac{\chi_{exact} - \chi_{approx}}{\chi_{exact}} \simeq - \xi_1 \Delta\xi = -\xi_1{}^2 \frac{(y_2 - y_1)}{y_1} \qquad (21a)$$

Therefore for any ξ_1, ξ_2 for which the source length $y_2 - y_1$ is small compared to y_1, we can be assured that the relative error in using the point source formula is equal to or smaller than $(y_2 - y_1)/y_1$ (all other errors neglected).

3e. A Line Source with Limited Vertical Mixing

If the mixed layer has a finite height L, the unlimited mixing formulae developed in Sections 3a - 3d become less accurate as the distance y_1 exceeds x_L (defined in Section 2a). Since the derivation of a limited mixing line source formula for a wind parallel to the source involves several approximations, it may be preferable to represent all line segments having $y_1 > x_L$ as point sources, provided they obey the criteria of Sect. 3d. In these circumstances x_L is defined as a distance from the source along the wind direction rather than along the x axis.

3f. Applications of Line Source Models

The preceding equations can be applied to a network of roads or streets, particularly if they are parallel or perpendicular to one another. Close to a roadway, model accuracy suffers since the concentration depends strongly on the plume dispersion width at the source. This is a function of local turbulence created by the traffic and by heat flux from the pavement, motors and exhaust. Furthermore, the source resembles an area rather than a line. The presence of buildings will further complicate the picture.

If the road network is nonuniform, then it will be more efficient to model the nearby roads as lines, and the remote ones as points. If the network is dense, then the remote roads can be blended into area sources.

Three highway models are compared in a paper by Noll et al. (1978). One of these, the EPA HIWAY model, simulates all roads as a series of point sources. The California model and the CALINE 2 model utilize concepts developed in the preceding sections.

AREA SOURCE MODELS

A formal expression for the concentration field downwind of an area source can be derived by considering the area to be made up of a series of line sources. The net concentration is the integral of the concentrations from each line source. In practice, an area source may consist of a large number of small emitters, such as a housing area in a city. For a receptor close to an area source, the source appears to be infinite in the crosswind direction. Crosswind diffusion can be neglected, simplifying the formula. Far away, the area source begins to resemble a point source. If there are many area sources of approximately equal strength adjacent to one another, pollutants dispersed laterally from one source are replaced by lateral dispersion from adjacent sources. The net effect allows one to neglect lateral dispersion and to use a formula for an infinite crosswind area source based on the emission rates of the area sources directly upwind.

If the area source strength is Q_α kgm $m^{-2}S^{-1}$, then the concentration $d\chi(x,o,o)$ due to a line element located at x' can be found from the line source equation Eq. (11).

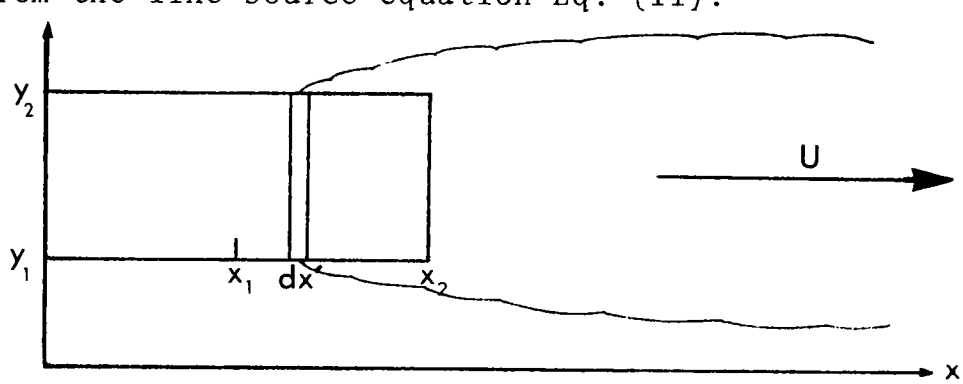


Fig. 7

$$d\chi(x,o,o) = \frac{Q_\alpha}{(2\Pi)^{1/2} U\sigma_z} \frac{dx'}{(x-x')} \left\{ \mathrm{erf}\left(\frac{y_2}{\sqrt{2}\sigma_y(x-x')}\right) - \mathrm{erf}\left(\frac{y_1}{\sqrt{2}\sigma_y(x-x')}\right) \right\} \tag{22}$$

Since the error function terms vary slowly relative to $\sigma_z(x-x')$ as x' changes, they are not included in the integration. Assuming that σ_z varies linearly with x as in Eq. (16), we find

$$\chi = \frac{Q}{(2\Pi)^{1/2}\sigma_z(x)U}\alpha\frac{x}{} \ln \frac{\sigma_z(x)}{\sigma_z(x-x_2)} \left[\mathrm{erf}\left\{\frac{y_2}{\sqrt{2}\sigma_y(x-x_1)}\right\} - \mathrm{erf}\left\{\frac{y_1}{\sqrt{2}\sigma_y(x-x_1)}\right\}\right] \tag{23}$$

where x_1 is arbitrarily chosen as $x_2/2$.
Care must be taken not to allow σ_z to vanish in the denominator when x approaches x_2. Since most plumes have a finite size at the source, σ_z can be expressed as $\sigma_z(x-x_2+x_o)$ where x_o is the distance from a virtual origin that gives σ_z the correct thickness at $x=x_2$.

Far from the source, when the erf terms approach each other or when $\sigma_z(x)$ approaches $\sigma_z(x-x_2)$, the erf and log terms are more accurately evaluated by their asymptotic expansions. If we write $\sigma_z(x) = \sigma_z(x-x_2) + \Delta\sigma_z$, the log term can be expanded to give

$$\chi = \frac{Q}{(2\Pi)^{1/2}\sigma_z(x)U}\alpha\frac{\Delta x}{} \left[\mathrm{erf}\left\{\frac{y_2}{\sqrt{2}\sigma_y(x)}\right\} - \mathrm{erf}\left\{\frac{y_1}{\sqrt{2}\sigma_y(x)}\right\}\right]\left\{1 - \frac{1}{2}\frac{\Delta x}{x}\right\} \tag{24}$$

where $\Delta x = x_2$, the length of the area source. This is identical to the line source model with an error term. In order to keep the relative error less than ε, we can use the line source formula provided that

$$\frac{\Delta x}{x} \leq 2\varepsilon \tag{25}$$

Furthermore, as we saw in Section 3d, the area source may be represented by a point source with a relative error less than ε provided that Eq.'s (20a), (21a), and (25) are kept less than ε.

CHEMICAL DECAY AND DEPOSITION

The concentration of a pollutant is diminished by the combined processes of diffusion, chemical decay, and deposition. Diffusion dominates near the source and has been treated in the preceding sections. If the pollutant is unstable and changes to another species via a first order reaction described by the term $R_1 = -k\,\chi$ kgm m^{-3} s^{-1}, chemical decay will eventually become significant. Wet deposition causes a similar reduction in concen-

tration. If we examine only washout, rain removes pollutants at a rate R_2 proportional to their concentration, ie, $R_2 = -\lambda\ \chi$. (We will not consider rainout in the present model in which pollutant particles act as nuclei for raindrop formation). Dry deposition is the process of surface absorption of pollutants. This surface flux is expressed as $\chi\, v_d$ (v_d = deposition velocity).

It will simplify our analysis if we assume the plume to be uniformly mixed in the vertical direction. This assumption is valid for most of the plume's lifetime and fails only in the region close to the stack, ie., for $x < x_L$.

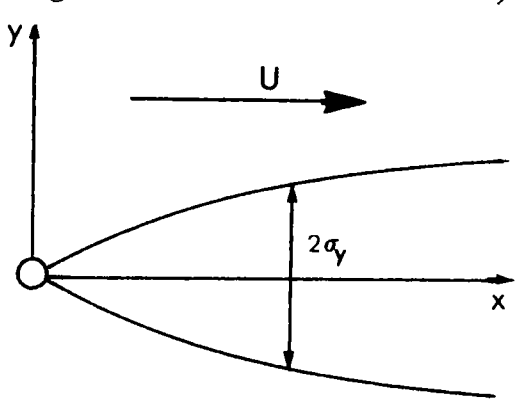


Fig. 8a (Top View)

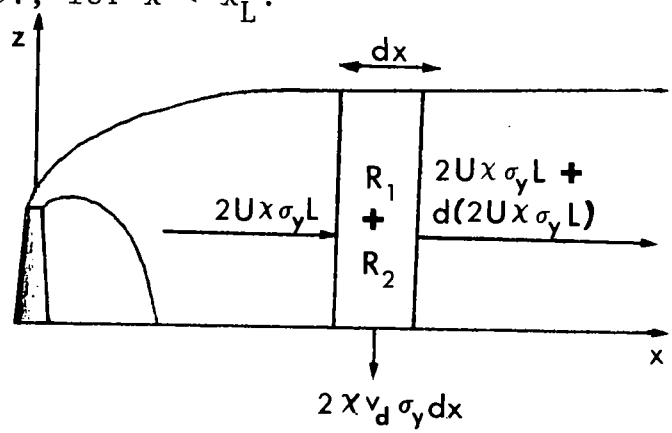


Fig. 8b (Side View)

If we further assume for analytical simplicity that the plume material is uniformly distributed in the horizontal direction over a distance $2\sigma_y(x)$, we can generalize the results later to more accurate plume models. The equation for conservation of mass is written as

$$\frac{\partial \chi}{\partial t} + \frac{\partial}{\partial x_\alpha}(\chi\ U_\alpha) = R_1 + R_2 \qquad (26)$$

Assuming the meteorological and concentration fields to be steady in time, and using Gauss's divergence theorem to integrate the left side of Eq. (26) over the control volume of Fig. 8b, the mass fluxes leaving through the sides of the control volume are related to production rates within the volume:

$$\underbrace{d(2U\chi\sigma_y L)}_{\text{net mass loss in x direction}} + \underbrace{2v_d\chi\sigma_y dx}_{\text{mass lost to ground}} = \underbrace{-(k + \lambda)2\chi\sigma_y L dx}_{\text{chemical decay and washout}} \qquad (27)$$

This can be integrated to give

$$\ln \frac{\chi \sigma_y}{(\chi\sigma_y)_o} = -\frac{\alpha x}{U} \qquad \left\{\alpha = k + \lambda + \frac{v}{L}d\right\} \tag{28}$$

Since there is no loss at the source, $Q = \chi_o\ U\ L\ 2\ \sigma_{y_o}$ where the subscript zero refers to conditions at or near the source.

$$\chi = \frac{Q}{2LU\sigma_y} \exp\left(-\frac{\alpha x}{U}\right) \tag{29}$$

The concentration which would exist due to diffusion alone is given by putting $\alpha = o$. We can generalize these results by multiplying any of the Gaussian concentration formulae in the previous sections by $\exp(-\alpha x/U)$ to account for removal processes. A similar analysis can be done to describe the formation of a secondary pollutant (ie., SO_4 from SO_2). Knowing the concentrations and the deposition rates, the amount of pollutant transferred to the surface can be calculated.

An alternate approach which gives less physical insight into the problem is to assume that the general solution to the diffusion-reaction equation is simply the product of the Gaussian solution and an exponential decay term. This solution, given by the expression

$$\chi = \chi_G \exp(-\alpha x/U)$$

can be verified by inserting it into the diffusion-reaction equation, having a constant diffusivity K and a first order reaction rate $R = -\alpha\ \chi$, ie.,

$$U \frac{\partial \chi}{\partial x} = K \frac{\partial^2 \chi}{\partial y^2} + K \frac{\partial^2 \chi}{\partial z^2} + R$$

The Gaussian solution χ_G satisfies the equation

$$U \frac{\partial \chi_G}{\partial x} = K \frac{\partial^2 \chi_G}{\partial y^2} + K \frac{\partial^2 \chi_G}{\partial z^2}$$

ERROR ESTIMATES

An interesting exercise is to take the Gaussian dispersion equation and estimate what is the expected error in χ due to all

the errors in estimating components of the equation such as σ_y, σ_z, U, H, Q, and lateral plume position. These are errors of measurement and cause errors in calculating χ even if the Gaussian distribution describes the physical plume perfectly.

Suppose the variable χ is a function of m variables η_1, η_m such that the differential can be written as

$$d\chi = \sum_{j=1}^{m} \frac{\partial \chi}{\partial \eta_j} d\eta_j = \sum_{j=1}^{m} a_j \tag{30}$$

where a_j is small and may be positive or negative. In this equation $d\chi$ is the error associated with specific errors a_j in each of the differential terms. If such an error estimate is made in N different trials, then the mean square error e^2 to be expected in any evaluation of χ is

$$e^2 = \frac{1}{N} \sum_{i=1}^{N} (d\chi_i)^2 = \sum_{j=1}^{m} \overline{a_j}^2 \tag{31}$$

where $\overline{a_j}^2$ is the mean square error of the jth error term and is written as

$$\overline{a_j}^2 = \frac{1}{N} \sum_{i=1}^{N} a_{ij}^2 \tag{32}$$

and where the mean of cross product terms $a_{ij}\, a_{kl}$ is zero.

The differential of the plume equation Eq. (5) for a ground level estimate (z=0) is found to be

$$\frac{d\chi}{\chi} = \frac{dQ}{Q} - \left(\frac{y}{\sigma_y}\right)^2 \frac{dy}{y} - \left(\frac{H}{\sigma_z}\right)^2 \frac{dH}{H} + \left(\frac{y}{\sigma_y}\right)^2 \frac{d\sigma_y}{\sigma_y} - \frac{d\sigma_y}{\sigma_y} + \left(\frac{H}{\sigma_z}\right)^2 \frac{d\sigma_z}{\sigma_z} - \frac{d\sigma_z}{\sigma_z} - \frac{dU}{U} \tag{33}$$

The mean square of this ratio is, from Eq. (31), the sum of the mean sqares of each of the error terms on the right side of Eq. (33).

$$e^2 = \overline{\left(\frac{d\chi}{\chi}\right)^2} = \overline{\left(\frac{dQ}{Q}\right)^2} + \overline{\left(\frac{y^2}{\sigma_y^2}\frac{dy}{y}\right)^2} + \overline{\left(\frac{H^2}{\sigma_z^2}\frac{dH}{H}\right)^2} + \overline{\left(\frac{y^2}{\sigma_y^2}\frac{d\sigma_y}{\sigma_y}\right)^2} + \overline{\left(\frac{d\sigma_y}{\sigma_y}\right)^2} + \overline{\left(\frac{H^2}{\sigma_z^2}\frac{d\sigma_z}{\sigma_z}\right)^2} + \overline{\left(\frac{d\sigma_z}{\sigma_z}\right)^2} + \overline{\left(\frac{dU}{U}\right)^2} \tag{34}$$

$$\overline{(.05)^2} \quad \overline{(1)^2(.1)^2} \quad \overline{(1)^2(.2)^2} \quad \overline{(1)^2(.2)^2} \quad \overline{(.2)^2} \quad \overline{(1)^2(.2)^2} \quad \overline{(.2)^2} \quad \overline{(.2)^2}$$

Note how the relative sizes of y and σ_y affect the second and fourth error terms, and how the ratio of H to σ_z affects the third and sixth error terms. These reflect the sensitivity of the exponential terms to errors in estimating the position of the receptor relative to the plume centerline.

If the receptor is positioned so that $\sigma_y \simeq y$ and $\sigma_z \simeq H$, and if our error estimates for the remaining terms are as printed above each term, then the root mean square (RMS) of the relative error in χ is given by

$$e = (.2525)^{\frac{1}{2}} = .50$$

NON-UNIFORM METEOROLOGICAL OR TERRAIN CONDITIONS

In Section 1, it was stated that the necessary conditions for a Gaussian description of pollutant dispersal were homogeneity (uniformity in space) and stationarity (uniformity in time). As the atmosphere becomes less uniform, it is very difficult to say at what point the Gaussian description becomes untrustworthy. If the terrain is uniformly rough, as characterized by a large surface roughness length z_o, then the Gaussian model is still applicable and uses dispersion coefficients which reflect the increased roughness

If the terrain is gently rolling, wind speeds and directions will be altered in the vicinity of hills. Although a plume will approach the surface slightly when passing over a hill, the wind speed will increase, tending to offset an increase in concentration. The flat terrain Gaussian models should then give reasonable ground level concentrations with respect to the plume centerline. If the horizontal wind direction is known, then the plume can be assumed to follow the wind. A description of some modified Gaussian models that attempt to cope with terrain problems is given in a review entitled "Turbulent Diffusion in Complex Terrain", by Egan (1975).

Egan also describes some plume experiments over very rugged terrain in Huntington Canyon. Topographic height variations in the area were from 1000 to 1500 meters. Centerline concentrations averaged over one minute were measured by helicopter. When

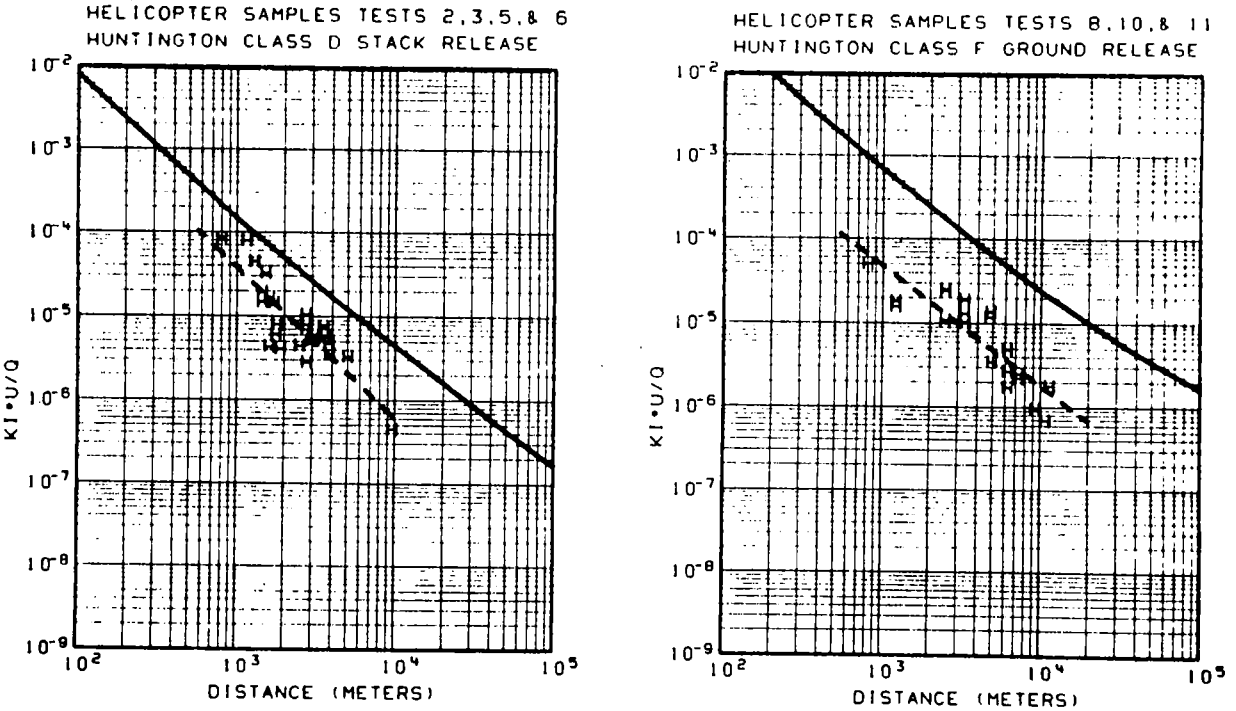


Fig. 9. Normalized centerline concentration vs. downwind distance in mountainous terrain, comparing a Gaussian prediction (solid curve) with helicopter measurements (H).

plotted against results predicted using a Gaussian model and Pasquill-Gifford dispersion coefficients, the measured values are much lower (Fig. 9). If they were converted to hourly averages, they would be lower still. However, it is encouraging that the slope of concentration with downwind distance is similar to the predicted curve, leading to speculation that an improved knowledge of σ_y and σ_z will lead to reasonable estimates of centerline concentrations over very rough terrain.

A similar problem of nonuniform flow is induced by the thermal contrast between a land and a water surface. A local circulation develops which will modify that due to the large scale regional wind. The local circulation is very time-dependent, since it is fed by the surface heat flux which changes with sun angle. A Gaussian model called GLUMP is described by Lyons (1975) in which the vertical direction is divided into six layers. Each layer has its own wind speed and direction, which allows for a partial description of the effect of wind shear on dispersion. Any source or virtual source which is located in a layer after considering the plume rise will generate a plume which remains within that layer. Meteorological conditions are averaged over

successive one hour periods and change discontinuously after each hour. If the breeze is onshore, a thermal internal boundary layer will grow with distance inland. The height of the boundary layer and the stability characteristics of each of the six model layers must be determined.

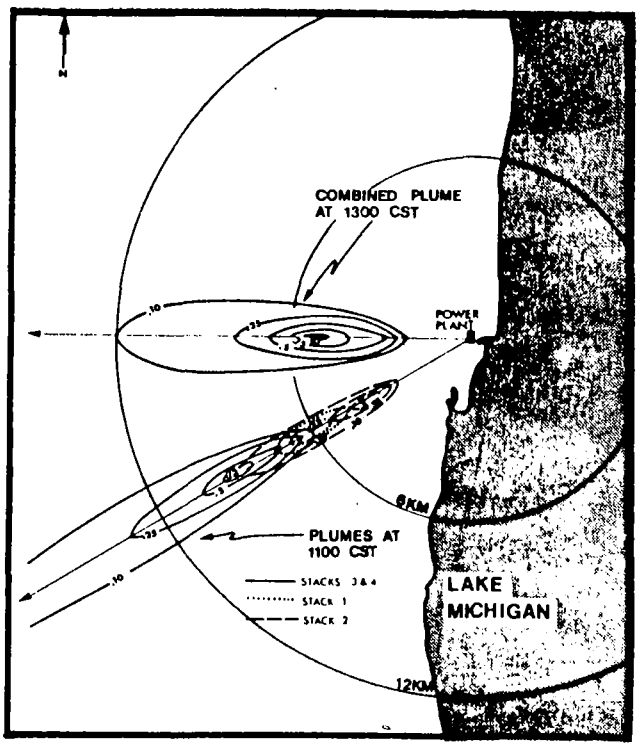


Fig. 10a. Surface isopleths at 1100 and 1300 hours averaged over 1 hour.

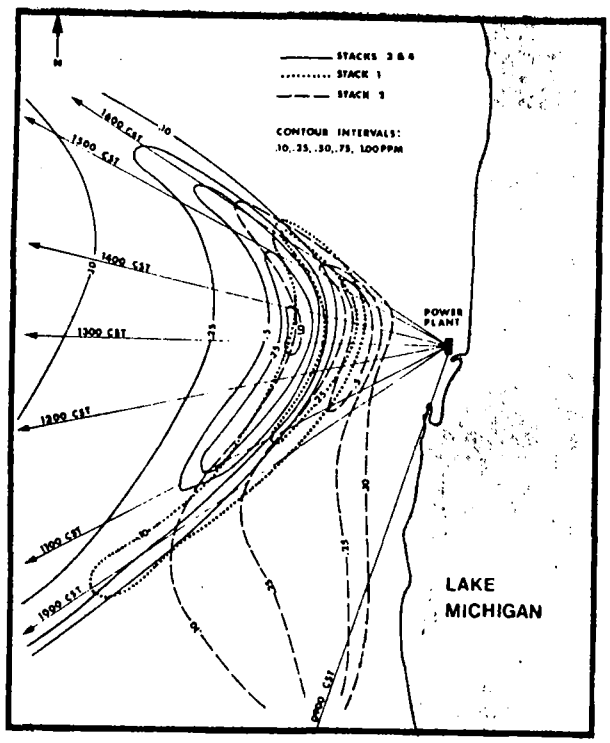
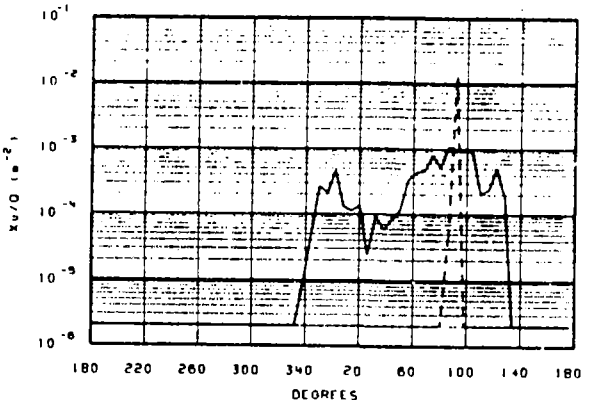


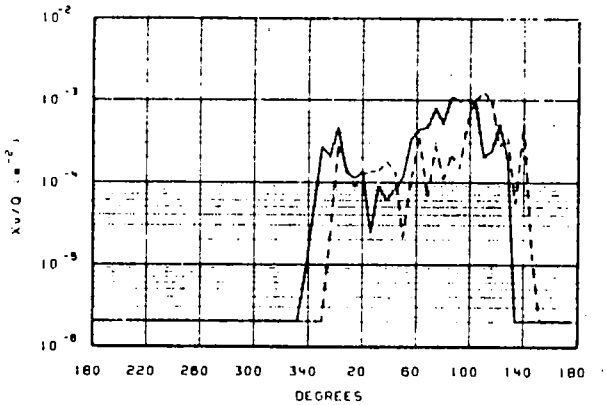
Fig. 10b. Surface isopleths averaged over 8 hours.

Surface isopleths from the model are shown in Fig. 10. In this case, there is no wind shear with height. Fig. 10a shows the results from a run at 1100 hours and at 1300 hours. When the concentration patterns of 8 successive hours are superimposed and averaged, Fig. 10b results.

Another interesting application of a Gaussian model to very unsteady conditions is in modelling diffusion under low wind speed, inversion conditions (Sagendorf and Dickson, 1976). Called the "segmented plume method", the meteorological conditions during the one hour test were divided into a series of two minute segments during which wind speed and direction were averaged. In addition to this, a "split-sigma" approach was used in which σ_y



(a) Standard Gaussian model



(b) Segmented plume model

Fig. 11. A comparison of measured (solid) and predicted (dashed) concentration profiles.

was determined from the two minute average of the azimuthal wind variance, and σ_z was determined from a scheme dependent on the vertical temperature gradient. Fig. 11a shows the result of a standard Gaussian calculation using meteorological conditions averaged over one hour. Fig. 11b shows the segmented plume results which are a composite of 30 separate runs, each representing a two minute average. There is a distinct improvement in the distribution of predicted concentrations.

Concentration results from a point source using a Gaussian model and a finite difference numerical model were compared to measured data in nonuniform terrain (Fabrick et al, 1977). The Gaussian model was accurate to within a factor of 2 or 3, and the grid model to within a factor of 2 over complex terrain. In a coastal region, the grid model accuracy remained about the same, with Gaussian model accuracy dropping to within a factor of 3 or 4.

It seems then that Gaussian models are of considerable use even in nonuniform conditions, provided one is aware of the magnitude of the errors in the results.

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PLUME RISE ESTIMATES: THEORY AND CURRENT PRACTICE

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INTRODUCTION

One essential parameter for the determination of the ground concentrations of pollutants is the effective stack height H. H is equal to the physical height of the stack (h) (See Appendix I for definition of symbols) plus the additional height to which the plume rises (Δh) or:

$$H = h + \Delta h \tag{1}$$

Bosanquet and Pearson (1936) indicated that the maximum ground level concentration of pollutants (C_{max}) is inversely proportional to H^2. This can easily be seen by the use of Equation (2).

$$C\ (x,\ y,\ z) = \frac{Q}{2\pi\bar{U}\sigma_y\sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_y^2}\right)\right] \tag{2}$$

C_{max} is given as

$$\frac{C_{max}}{Q} = \frac{2}{\pi e\bar{U}} \left(\frac{\sigma_z}{\sigma_y}\right) \left(\frac{1}{H^2}\right) \tag{3}$$

Here e = 2.718, is the base of the natural logarithms. It is assumed that the ratio (σ_z/σ_y) is independent of the downwind distance but varies with the sampling time. With an increase in H, C_{max} decreases.

PLUME GEOMETRY AND RISE

Once a puff is released from a point source it will move away from it with a speed and direction determined by the

wind. Because of mixing the puff will expand about its center at a rate depending on the scale of turbulence as it moves downwind.

If the atmospheric eddy size is smaller than the puff, both the puff and turbulent elements will be carried along with the mean large-scale motion (indicated by an arrow in Figure 1 A). In this case the puff will grow slightly and decreases its concentration. On the other hand if the eddies are larger than the puff, the puff will experience transport and less mixing (Figure 1 B) and its concentration remains the same.

If the eddies are of the same size as the puff, the puff will diffuse rapidly and change its shape (Figure 1 C).

Atmospheric turbulence play then an important role in behaviour of the puff. The size and scale of the turbulent motion will depend on the change of wind direction and thermal stability.

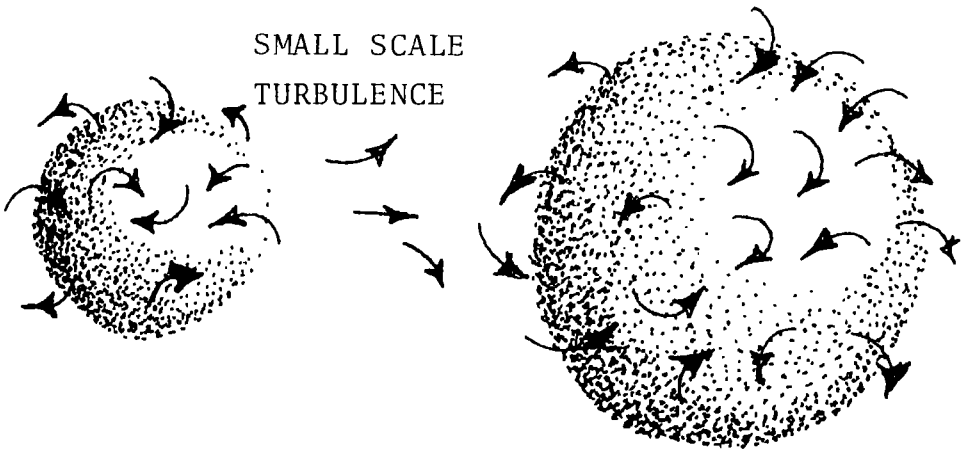
A continuous plume can be considered as one that is made up of an infinite number of puffs released from a fixed point source and hence, the plume behaves in a manner similar to the puff under different atmospheric conditions.

Depending on the variations of wind direction and temperature the plume may take one of the following forms (this topic has been discussed also in previous lectures) Figure 2.

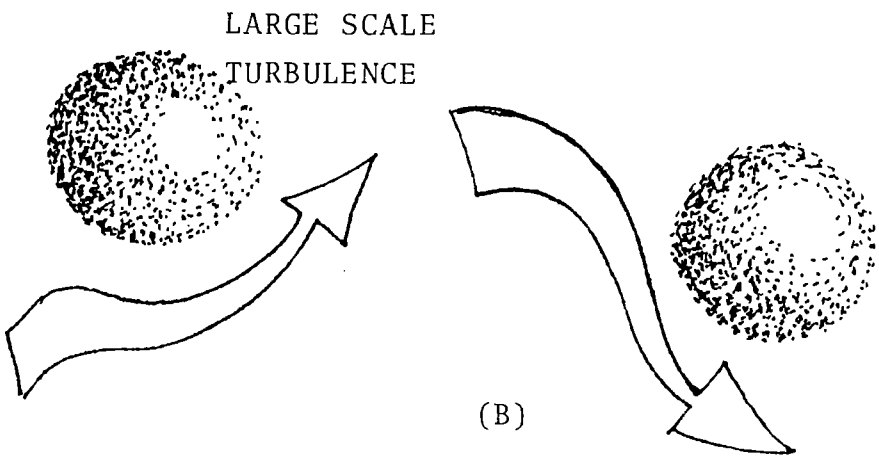
Five types of plume behaviour occur under different meteorological conditions within the diurnal cycle:

a) The coning plume occurs usually under neutral atmospheric conditions (Figure 2a). The verical temperature gradient is between isothermal and adiabatic. Coning of the plume favours cloudy and windy conditions and it may occur infrequently in a dry climate.

b) The plume is fanned when it is trapped by an inversion layer and disperses at its base (Figure 2b). The atmosphere is stable. This phenomena occurs during the evening, all night, or early in the morning.

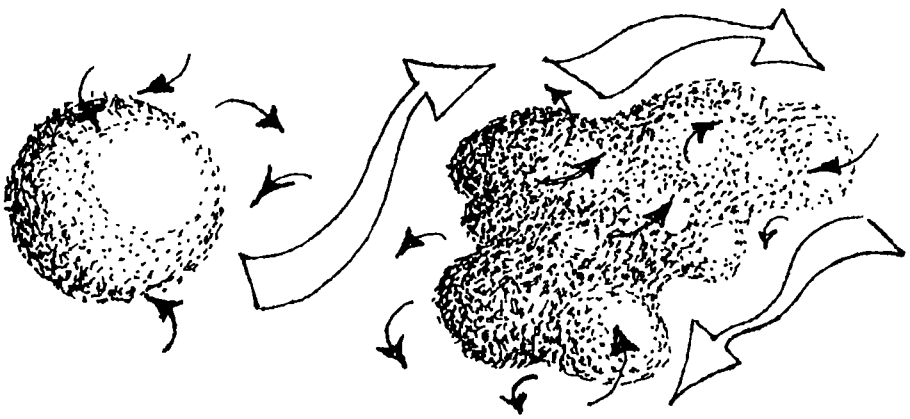


(A)



(B)

LARGE & SMALL SCALE TURBULENCE



(C)

Figure 1. Dispersion of a puff of smoke in a turbulent atmosphere.

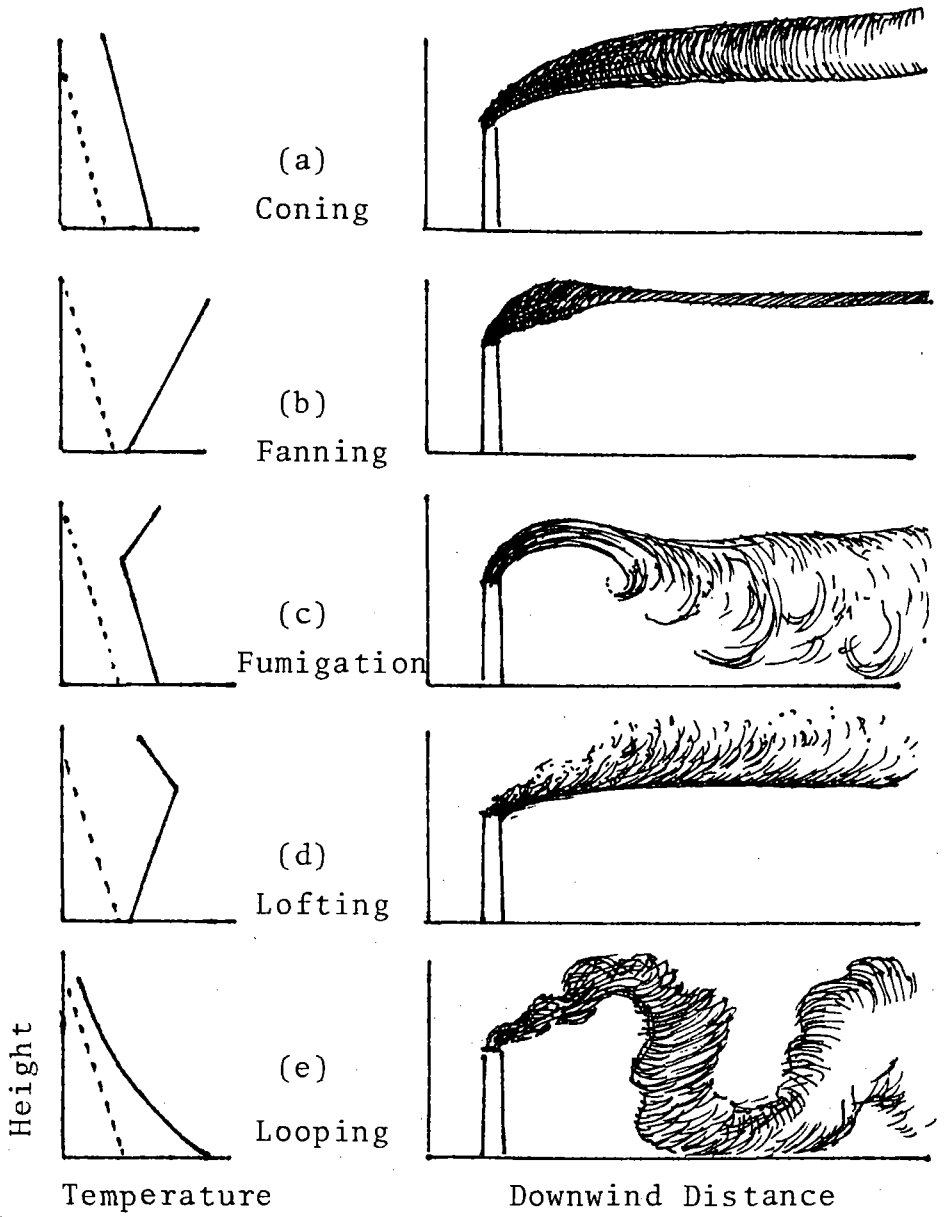


Figure 2. Various types of smoke-plume patterns under different meteorological conditions.

c) Shortly after sunrise the atmospheric layer under the inversion base slowly becomes thermally unstable. The thermal eddies, which develop in that layer, disperse the trapped plume and allow it to fumigate towards the ground (Figure 2c). The pollutants are dispersed uniformally in the layer. The condition can give rise to the highest ground-level concentrations. If the unstable layer does not grow, this condition may persist for a long time.

d) Under certain inversion conditions the buoyant plume may penetrate the inversion layer aloft. The plume continues its ascent in a lapse layer aloft and disperses above the inversion layer. The inversion acts as a barrier and prevents the plume from reaching the ground' the plume is loafting (Figure 2d).

e) In a light-wind warm condition, the atmospheric layer close to the ground is thermally unstable. The developed relatively large thermal eddies carry portions of the plume in a looping pattern (Figure 2e). During this looping condition part of the plume may reach the ground for a short period. At that time the ground-level concentration at the point of impingment will be high.

Buoyant plumes will rise to higher levels under calm conditions than for windy ones. In windy conditions downwash may occur (Figure 3), and the plume may be caught in the wake of a stack, a building or a topographical feature.

Sherlock and Stalker (1941) through their wind tunnel studies indicated that stack downwash may occur when

$$\frac{V_s}{U} \leq 1.5 \qquad (4)$$

For buoyant plumes, Briggs (1969) suggested that the

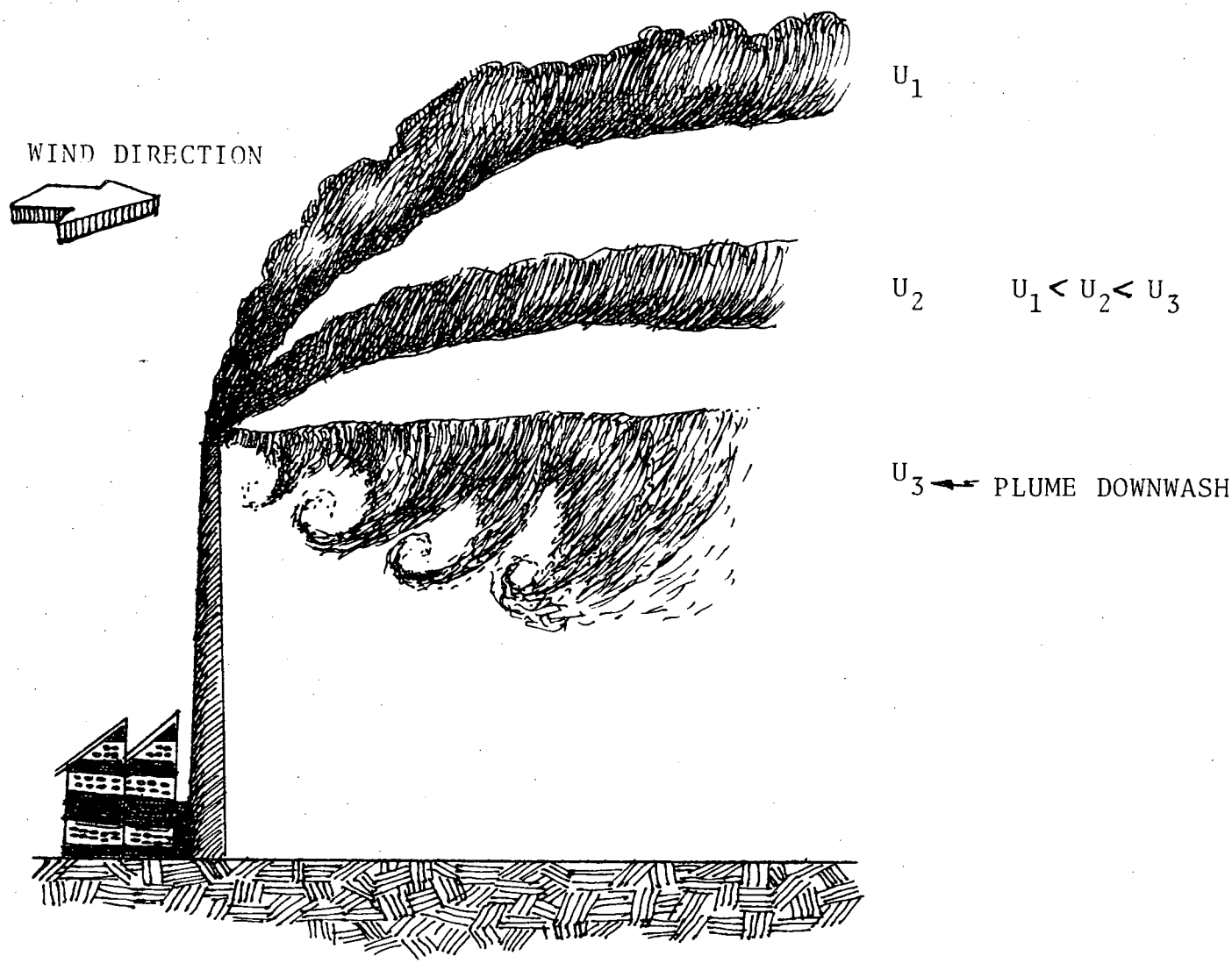


Figure 3. Different plume rise for different wind speed. For a large wind speed, the plume is caught in the wake behind the stack (downwash).

flux Froude (Fr) number given as

$$Fr = \frac{V_s^{\,2}}{g(\Delta T/T)D} \qquad (5)$$

should be less than 1 to avoid downwash. In such cases the buoyancy forces of the plume are sufficient to counteract the adverse pressure forces in the wake of the stack.

As a rule of thumb, Briggs (1969) suggests that the stack height should be 2.5 times the height of nearby buildings to avoid downwash.

In order to reduce the magnitude of the downwash problem Nonhebel (1960) recommends that V_s should be of the order of 6-8 m sec^{-1} for a small plant (10^6 cal sec^{-1}) and 15-18 m sec^{-1} for a large plant (10^7 cal sec^{-1}).

Trajectoris of the plume during its ascent under steady winds can be divided into four regions (Figure 4) (Csanady, 1965; Scorer, 1969;and Shwartz and Tulin, 1972). In the first region, the plume emerges as a jet with a vertical velocity that depends on its exist velocity and buoyancy, and has a circular cross section (Figure 4 A). Self-generated turbulence dominates its mixing with the environment. At a distance of 2 to 5 times the stack diameter, in the second region, the plume starts to bend downwind at a rate which depends on the strength of the wind. In this region the core of the plume rises faster than its periphery which is sheared off by the wind. The plume shape changes from a circular cross section to a well defined kidney shape (Figure 4 B). The plume tends to roll up behind the core downwind from the stack and two line vortices are formed which are of approximately equal strength but with opposite circulations. The subsequent behaviour of the plume depends on the type of interaction between the two line vortices and the surrounding air. Farther downstream the shape of the plume can deform slightly due to mixing (Figure 4 C). In the last region, the plume loses its momentum and buoyancy completely and becomes passive. As the plume motion weakens during its rise, the plume is greatly influenced by atmospheric condi-

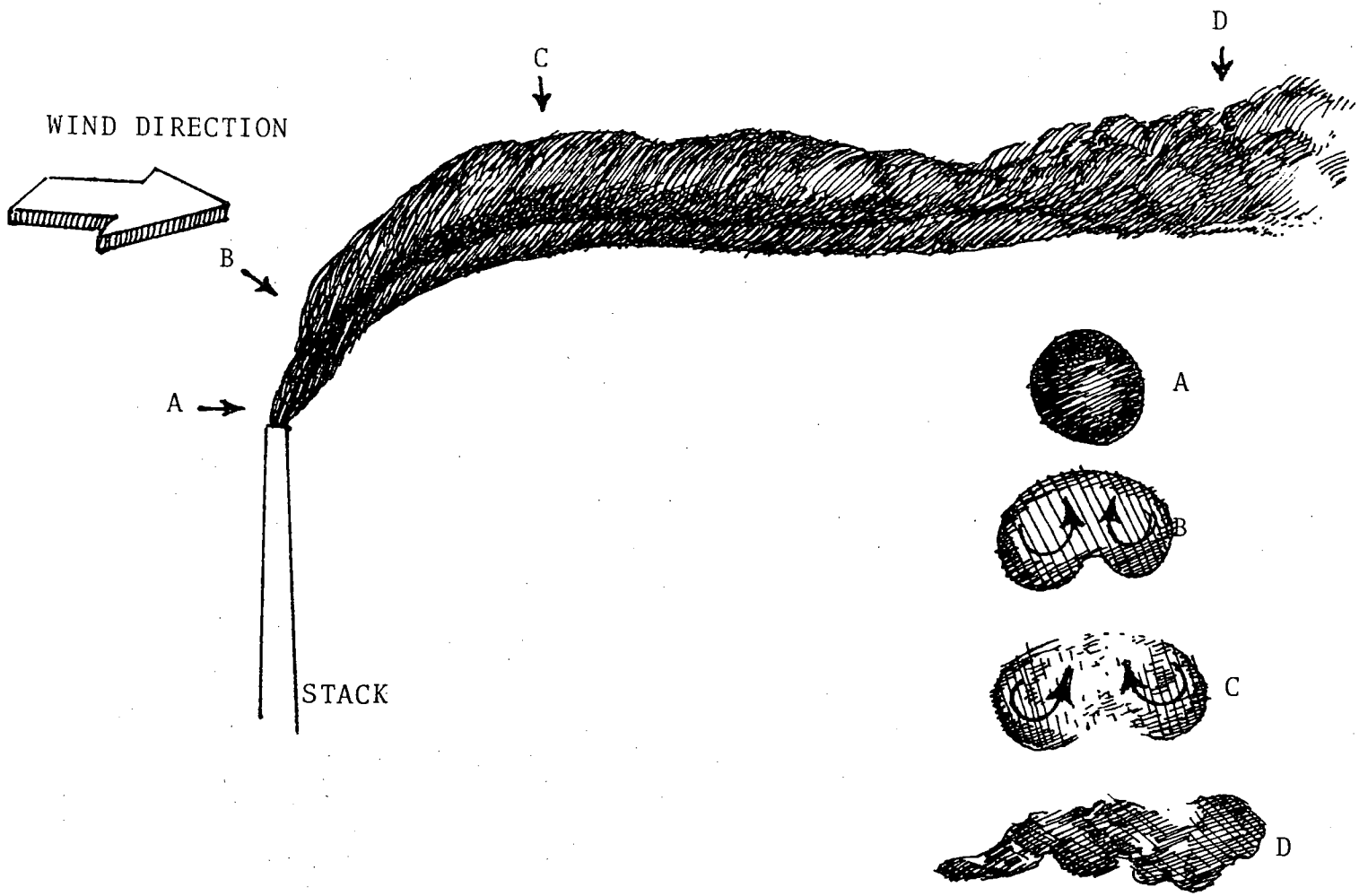


Figure 4. Characteristics of the plume cross-section at different regions in the plume. Arrows indicate the direction of circulation (after Scorer, 1968; and Shwartz and Tulin, 1972).

tions and moves horizontally with a lateral extent which is larger than its vertical extent (Figure 4 D). The Ambient turbulence destroys the vortex structure of the plume.

Briggs (1969) assumes that, the break down of the vortex structure occurs when the ambient turbulence energy dissipation rate equals that of the plume.

PLUME RISE FORMULAS

The determination of Δh is not well defined, for the smoke plume in the passive stage does not level off (Figure 4). Davidson (1961) assumed that Δh is equal to the height at which the slope of the plume is less than 0.1. Bosanquet (1957) defined Δh as the height at which the plume loses its momentum and buoyancy. Several formulas (over 100 formulas) have been prepared to determine Δh under different meteorological conditions. None of the formulas, however, appears to predict Δh successfully all the time. This is because the meteorological and topographical conditions are greatly simplified in these formulas (Briggs 1969, 1975b). Some of the formulas are based on theoretical or partially theoretical studies. Others are empirical.

The most complete theoretical study of the rise of plumes is the one developed by Priestley (1953). He introduced the plume as a column of turbulent air, in which heat mixes gradually with the environment until it is dissipated, a plume may rise to a few hundred meters in the troposphere and it may exist in both forced and free convection. His analysis (see Priestley 1959, p. 73) indicated that the plume motion may have three modes: that due to absolute buoyancy, oscillatory motion and asymptotic motion. These are governed by the environmental temperature and the diameter of the plume, so that two plumes of different diameters may behave differently in the same invironment.

Priestley and Ball (1955) considered a plume of circularly symmetric form with a gaussian distribution of temperature and velocity in the horizontal. Their analysis suggested

that the plume spreads its temperature excess radially outward from its core during ascent. Priestley (1956) extended this study to allow for wind effects' a light wind will incline the plume to the vertical and restrict its height. The warm core of the plume rises faster than the cooler circumference, and consequently the former is displaced a shorter distance downwind than the circumference. As a result, the circular cross-section changes to an oval cross-section which is elongated downwind. For strong winds, Ball (1958) observed that buoyant smoke plumes deteriorate into well-developed turbulence.

Priestley simplified the Navier-Stoke's equation of motion for a steady conditions to the following:

$$\frac{d}{dz}(R^2w^2) = aR^2\frac{\theta}{\theta_e}g \tag{6}$$

$$\frac{d}{dz}(R^2w^3) = bR^2w\frac{\theta}{\theta_e}g - cRw^3 \tag{7}$$

$$\frac{d}{dz}(R^2w\theta) = -dR^2w\frac{\partial\theta e}{\partial z} \tag{8}$$

where a, b, c and d are numerical expressions.

Note the above equations take into account the stability of the atmosphere in the term $\frac{(\partial\theta e)}{\partial z}$ Priestley discussed the solution for all cases of stability, however, for the neutral case $(\frac{\partial\theta e}{\partial z} = 0)$ the general solution is given as

$$w = \left(\frac{3}{2}\frac{Ag}{\theta_e C^2 Z} + \frac{B}{Z^3}\right)^{1/3} \tag{9}$$

$$\theta = \frac{A}{C^2Z^2}\left(\frac{3Ag}{2\theta_e C^2 Z} + \frac{B}{Z^3}\right)^{-1/3} \tag{10}$$

where A and B are given as

$$A = \frac{Q}{\pi g c_p} \tag{11}$$

and

$$B = w_o^3 z_o^3 - \frac{3Ag}{2\theta_e C^2} \tag{12}$$

and

$$z_o = \frac{D_o}{2C} \tag{13}$$

Priestley suggested that $c \propto U^{1/2}$ and assumed that C = 0.75 when U = 2.4 m sec^{-1}.

Most of the empirical formulas attempt to describe Δh in the following form:

$$\Delta h \propto \frac{Q^a}{U^b} \qquad (14)$$

where a and b are empirical constants. The constant of proportionality of the above equation differs from one formula to another. In general, however, it depends on the topography and on the atmospheric turbulence structure. Lucas (1967) suggested it is a function of Δh as well. For each formula, a and b differ, depending on the assumptions made within each stage of the plume.

These formulas may be applied to the rise of moist plumes as a first approximation. Briggs (1975b) indicated that the effect of latent heat release after plume condensation could be ignored.

The following is a list of selected plume rise formulas.

1 - Holland (1953) formula

Δh is given by

$$\Delta h = \frac{1.5 V_s d + 4\ 10^{-5} Q}{U} \qquad (15)$$

The first term describes the rise of a non-buoyant plume. The second term is added to describe the buoyancy effect on the rise of the plume. Q is the heat emission rate in cal sec^{-1}.

2 - <u>CONCAWE Formula</u> (Brummage 1968)

Δh is given by

$$\Delta h = 0.175 \frac{Q^{1/2}}{U^{3/4}} \qquad (16)$$

The formula is based on experimental observations for sources with Q <10 MW.

3 - Bringfelt (1968) Formulas

Depending on the downwind distance, Δh is given by

a) $\Delta h = \frac{103}{U} Q^{0.39}$ for $x \leq 250$ m (17)

b) $\Delta h = \frac{167}{U} Q^{0.36}$ for $250 < x \leq 500$ m (18)

c) $\Delta h = \frac{224}{U} Q^{0.34}$ for $500 < x \leq 1000$ m (19)

The heat emission rate Q is in MW.

4 - Moses and Carson (1968) Formula

In order to take into account atmospheric stability Δh is given by

$$\Delta h = A \left(-0.029 \frac{V_s d}{U} + 5.35 \frac{Q^{1/2}}{U}\right) \qquad (20)$$

where

A = 1.08 neutral atmosphere
= 0.68 stable atmosphere
= 2.65 unstable atmosphere

The heat emission rate Q is in κcal.

5 - Csanady (1961) Formula

Csanady in his analysis of the rise of plumes defined the initial momentum and buoyancy flux F as

$$F = g\, V_s \frac{d^2}{4} \frac{T_s - T}{T_s} \quad (m^4\ sec^{-3}) \qquad (21)$$

He also introduced a scaling length

$$\ell = \frac{F}{U^3} \quad (m) \qquad (22)$$

Csanady indicated that $\frac{\Delta h}{\ell}$ (non-dimensional form) is a function of $\frac{x}{\ell}$. A relationship in the form of a $\frac{2}{3}$ law appears to agree with his experimental observations, that is,

$$\frac{\Delta h}{\ell} = \left(\frac{x}{\ell}\right)^{2/3} \qquad (23)$$

6 - TVA 1971 and 1972

Two models for Δh were developed at the Air Quality Branch of the Tennessee Valley Authority by Montgomery et al (1971 & 1972). The formulas are based on a full-scale study

of plume rise from a large electric generating plant.

The first model follows that of Briggs and is based on the 2/3 law. The second however is not based on the 2/3 law but on a best fit to the experimental observations.

The formulas are,

$$\Delta h \text{ (TVA 1971)} = 114 \frac{CF^{1/3}}{U} \tag{24}$$

where $C = 1.58 - 41.4 \frac{\partial \Theta}{\partial z}$

and

$$\Delta h \text{ (TVA 1972)} = \frac{173F}{UE} \tag{25}$$

where $E = \exp\left(64 \frac{\partial \Theta}{\partial z}\right)$

7 - Briggs (1969, 1971 and 1972) Formulas

Briggs introduced different formulas for Δh depending on atmospheric stability, wind conditions and type of plumes.

(i) Non-Buoyant Plumes (jets)

(a) Stable atmosphere ($\frac{\partial \Theta}{\partial z} > o$)

Under calm conditions (U=o) the jet rises vertically without limit. Δh is given by

$$\Delta h = 4 \left(\frac{F_m}{S}\right)^{1/4} \tag{26}$$

where F_m is the moment flux parameter given as

$$F_m = \frac{T}{T_s} \frac{V_s^2 d^2}{4} \tag{27}$$

For windy conditions (U>o) h is given by

$$\Delta h = 1.44 \left(\frac{V_s d}{U}\right)^{2/3} x^{1/3} \tag{28}$$

The plume reaches a maximum height Δh_{max} equals to

$$\Delta h = 1.5 \left(\frac{F_m}{U}\right)^{1/3} S^{-1/6} \tag{29}$$

where S is a stability parameter given as

$$S = \frac{g}{T} \frac{\partial \Theta}{\partial z} \tag{30}$$

(b) Unstable and Neutral Atmosphere ($\frac{\partial\Theta}{\partial z} \leq o$)

For calm conditions the jet will rise without limit. For windy conditions (U>o) Δh is given by

$$\Delta h = 1.44 \left(\frac{V_s d}{U}\right)^{2/3} x^{1/3} \tag{31}$$

and the jet will reach a maximum height of

$$\Delta h = \frac{3V_s d}{U} \tag{32}$$

(ii) Buoyant Plumes

(a) Stable Atmosphere ($\frac{\partial\Theta}{\partial z} > o$)

Under calm conditions (U=o), Δh is given by

$$\Delta h = 5 \left(\frac{F^2}{S^3}\right)^{1/8} \tag{33}$$

where F is the buoyancy flux (see equation 11).

For U>o Briggs indicated that Δh depends on some downwind distance x_F where the mean temperature of the plume equals the ambient temperature. x_F is given by

$$x_F = \frac{\pi U}{\sqrt{S}} \tag{34}$$

For $x<x_F$ Δh is given by

$$\Delta h = \frac{1.6F^{1/3} x^{2/3}}{U} \tag{35}$$

For $x \geq x_F$

$$\Delta h = 2.4 \left(\frac{F}{US}\right)^{1/3} \tag{36}$$

(b) Unstable and Neutral Atmosphere ($\frac{\partial\Theta}{\partial z} \leq o$)

Briggs divided the rise of the plume according to some downwind distance x* which in turn depends on F.

For $F < 55$ $\quad x^* = 14\ F^{5/8}$

$F \geq 55$ $\quad x^* = 34\ F^{2/5}$

For $x < 3.5\ x^*$ Δh is given by

$$\Delta h = \frac{1.6F^{1/3}\ x^{2/3}}{U} \tag{37}$$

and for $x \geq 3.5\ x^*$

$$\Delta h = \frac{1.6F^{1/3}(3.5\ x^*)^{2/3}}{U} \tag{38}$$

DISCUSSION OF EXPERIMENTAL RESULTS

Moore (1974, 1975) and Briggs (1975a, 1975b) have re-examined predictive capability of existing plume rise formulas. Moore assumes that the rise of a plume is a three dimensional phenomenon and that the plume consists of a string of discrete lumps. It grows by mixing with the environment at a rate that is directly proportional to the plume height. He suggests that h is given by the relation:

$$\Delta h \propto \frac{Q}{U}^{1/4} (x^*)^{3/4} \tag{39}$$

where $x^*(m)$ is a function of downwind distance and atmospheric turbulence. Briggs, on the other hand, prefers a continuous model rather than the lump model (coning plumes and plumes under stable atmospheric conditions appear to be continuous in shape). For simplicity and for practical purposes, Briggs prefers to treat the rise of the plume as a two dimensional phenomenon. He claims that the "2/3 law", where Δh is given as:

$$\Delta h \propto F^{1/3}\ \frac{x}{U}^{2/3}$$

is as accurate in determining Δh as is the relationship of Moore (Equation 27). Here F is the buoyancy flux term and x is the downwind distance from the source.

In their practical application it is apparent, however, that the above mentioned formulas are idealized, and that one should expect unrealistic results when dealing with rough terrain and complex meteorological conditions.

In the Alberta Oil Sands Experimental Study, the most commonly used formulas, namely Briggs (1969, 1971, 1972), TVA

1971 and 1972 (Montgomery et al, 1971, 1972) Holland (1953), CONCAWE (Brummage 1968) and Moses and Carson (1967) were selected to examine their predictive capability in determining the rise of the GCOS plume. This was done by comparing the observed plume rise with the predictive value; the results are shown in Figures 5-10. Mean wind speed between the stack top and the top of the plume was used in the comparison. Values of the wind speed were obtained from the minisonde observations that were made at the Lower Syncrude complex. It can be seen by the scatter of the points in the figures that none of the models is a good predictor for the measured values. Briggs, TVA 1972, and Moses and Carsons formulas underpredict the rise of the plume, which will lead to overestimation of the maximum ground-level pollutant concentration. The reverse is true with the remaining formulas.

Similar disagreements have also been observed by other workers (see e.g. Thomas et al 1970 and Guldberg 1975).

The predictive capability of the formulas depends on the wind speed. Table 1 shows the mean values of the ratio of the observed plume rise to the predicted value of the plume rise for different ranges of wind speed. With all the formulas except Briggs's, the fit becomes steadily worse with increase in the wind speed.

Hills, valleys and lakes, cause spatial variations in climate. These features generate winds, create temperature inversions and influence the rise of the plume. Numerous examples of these phenomena and their effects on air pollution have been presented elsewhere (e.g., Munn, 1966; Atomic Energy Commission (U.W.), 1968; ASME, Air Pollution Control Division, 1973). For illustrative purposes some examples are given below.

Unfrozen lakes are usually warmer than their surroundings in winter, and they are usually cooler in summer. This thermal difference between the land and the water creates anomolies in winter snowfall, summer rainfall, and cloudiness in the vicinity of the lake shores. As a result, the scavenging of pollutants by precipitation in these areas requires special consideration.

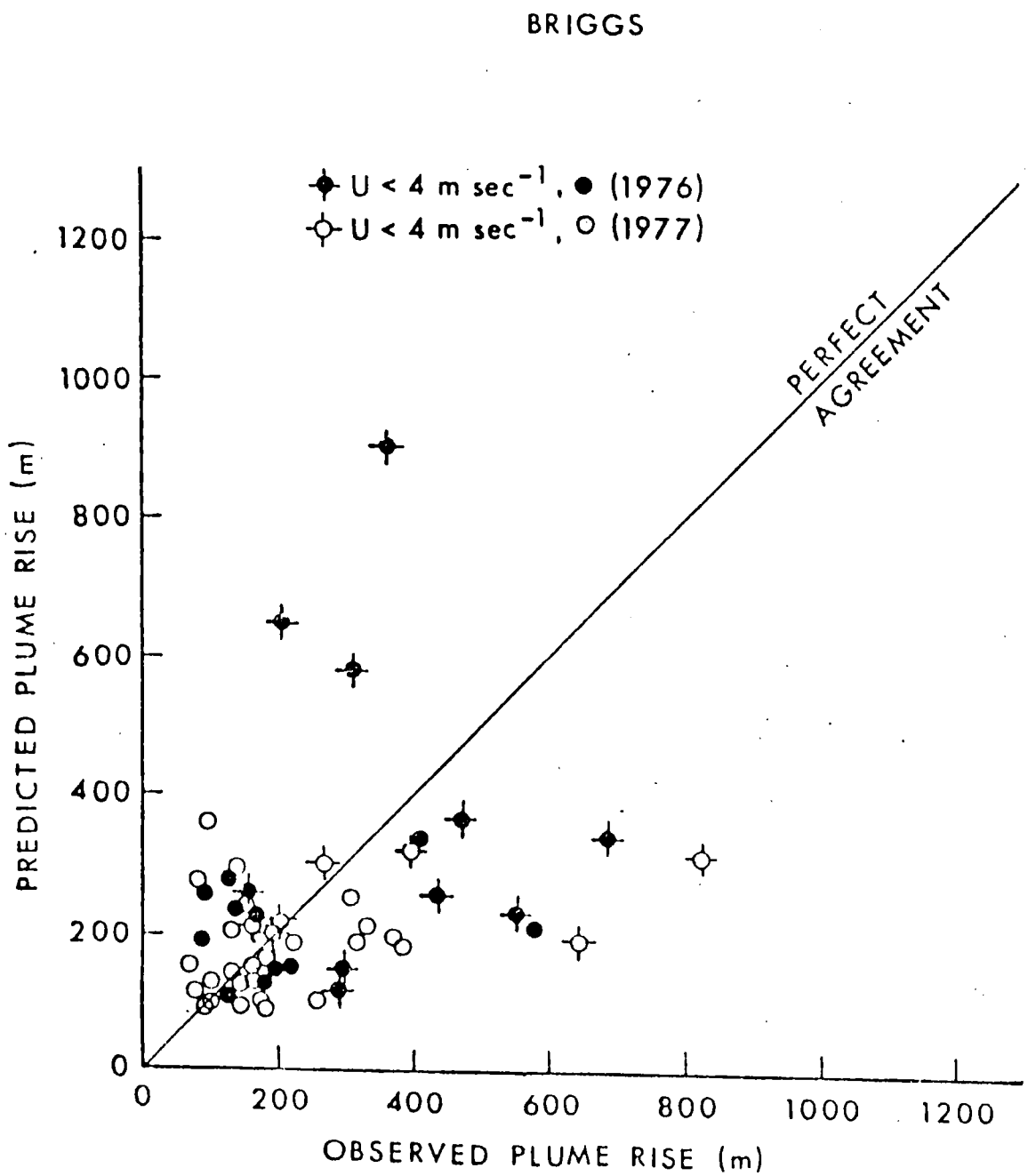


Figure 5. Comparison of predicted versus observed plume rise using Briggs' model. Solid line represents perfect agreement.

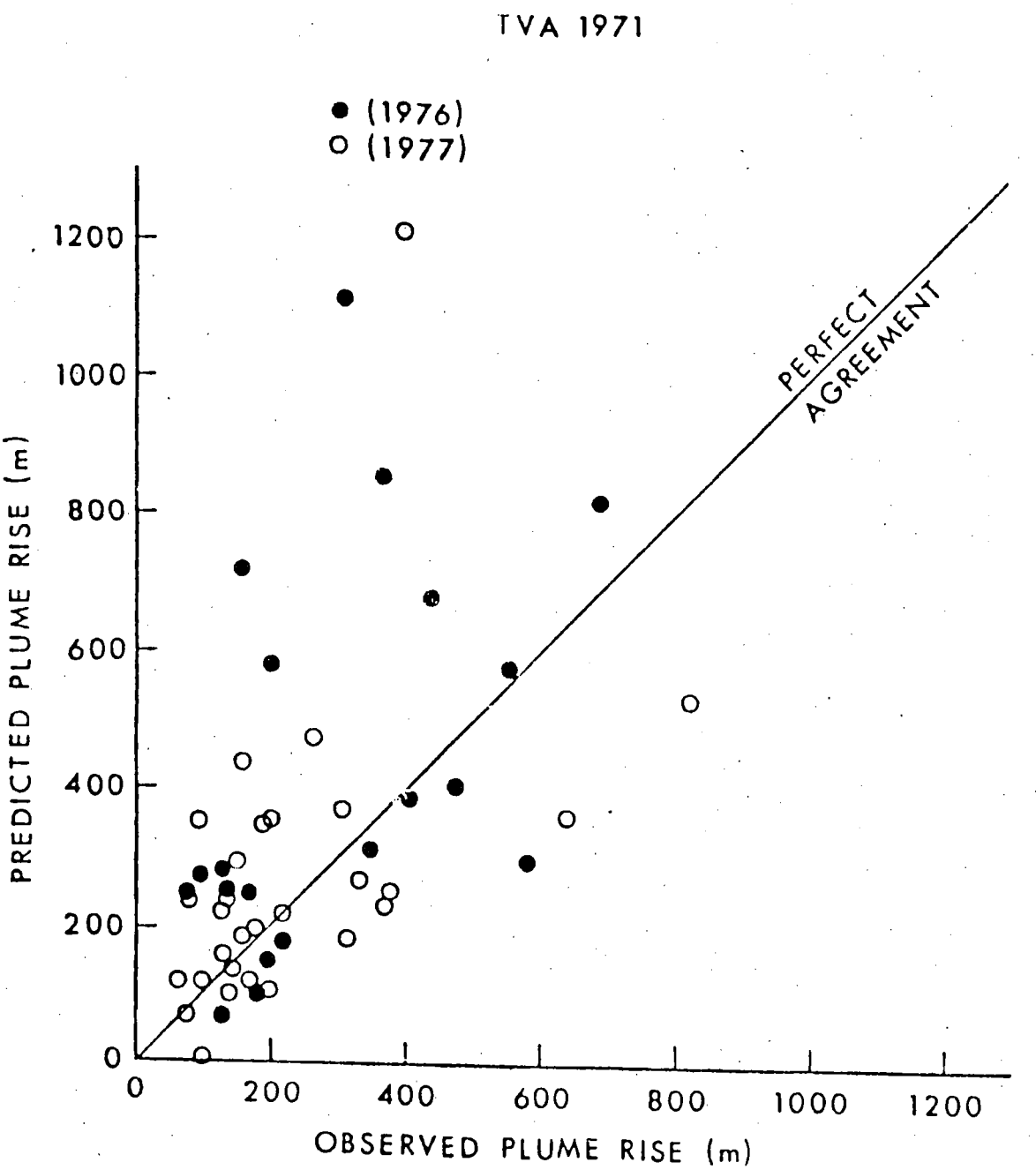


Figure 6. Comparison of predicted versus observed plume rise using TVA 1971 model. Solid line represents perfect agreement.

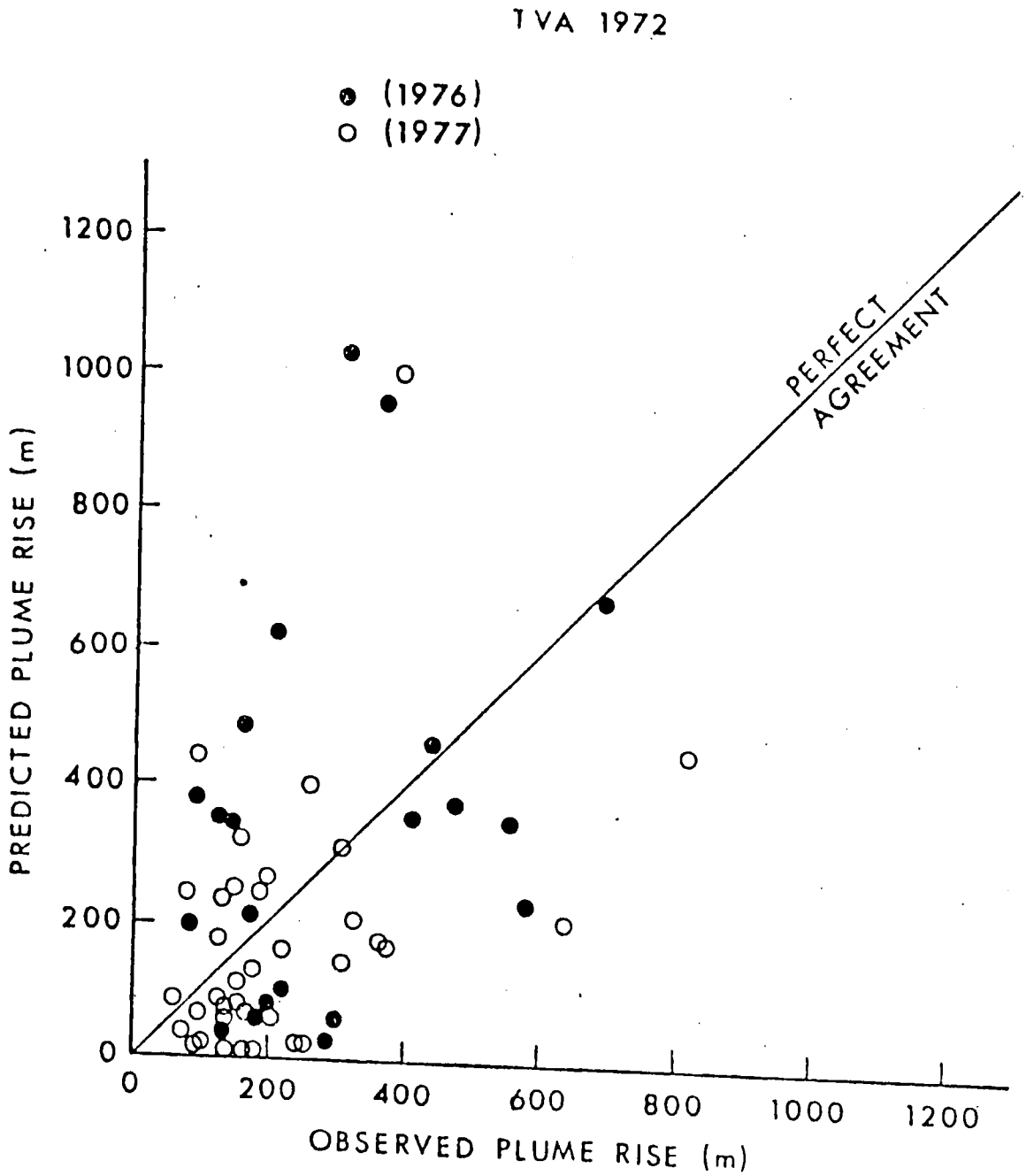


Figure 7. Comparison of predicted versus observed plume rise using TVA 1972 model. Solid line represents perfect agreement.

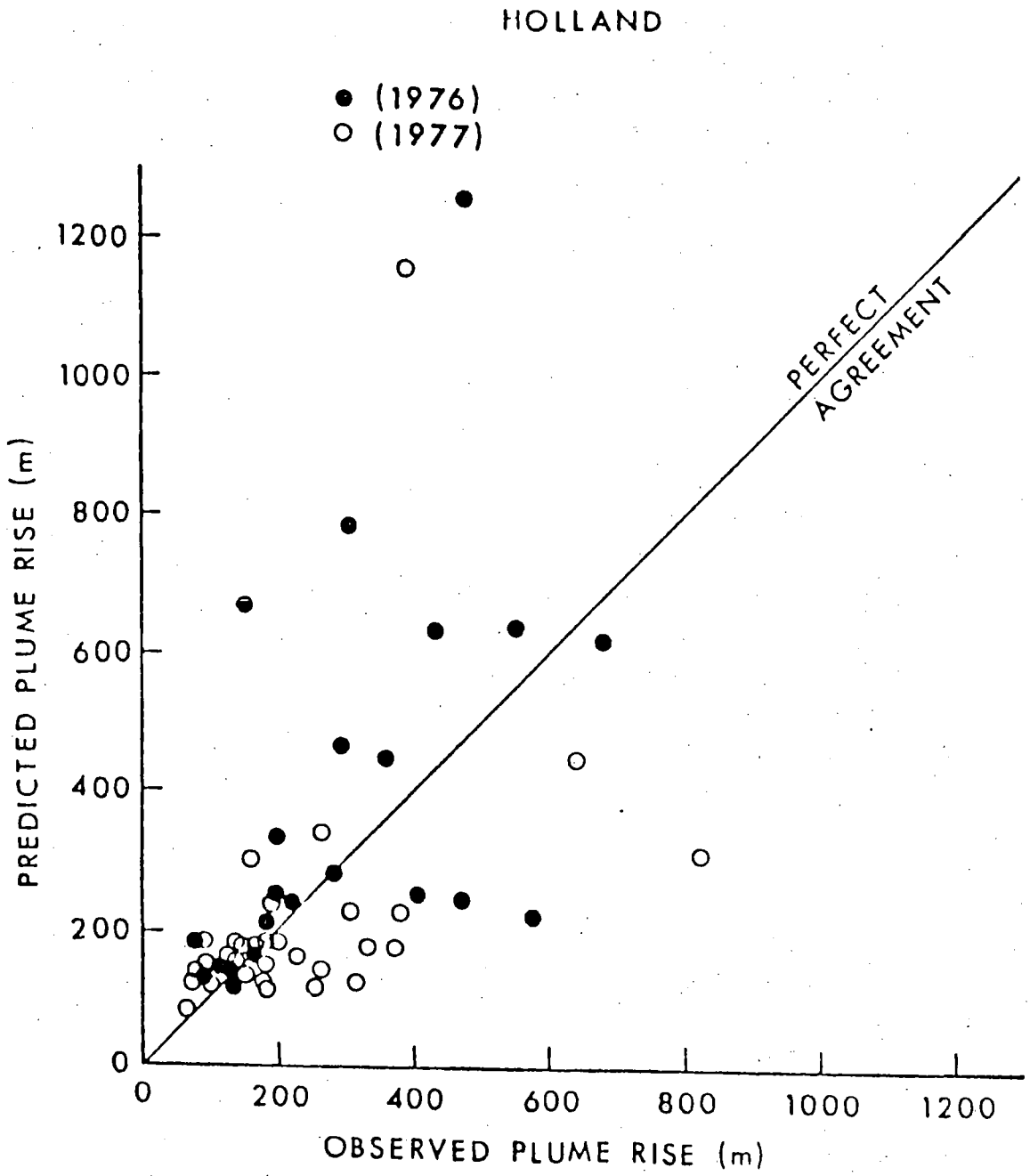


Figure 8. Comparison of predicted versus observed plume rise using Holland's model. Solid line represents perfect agreement.

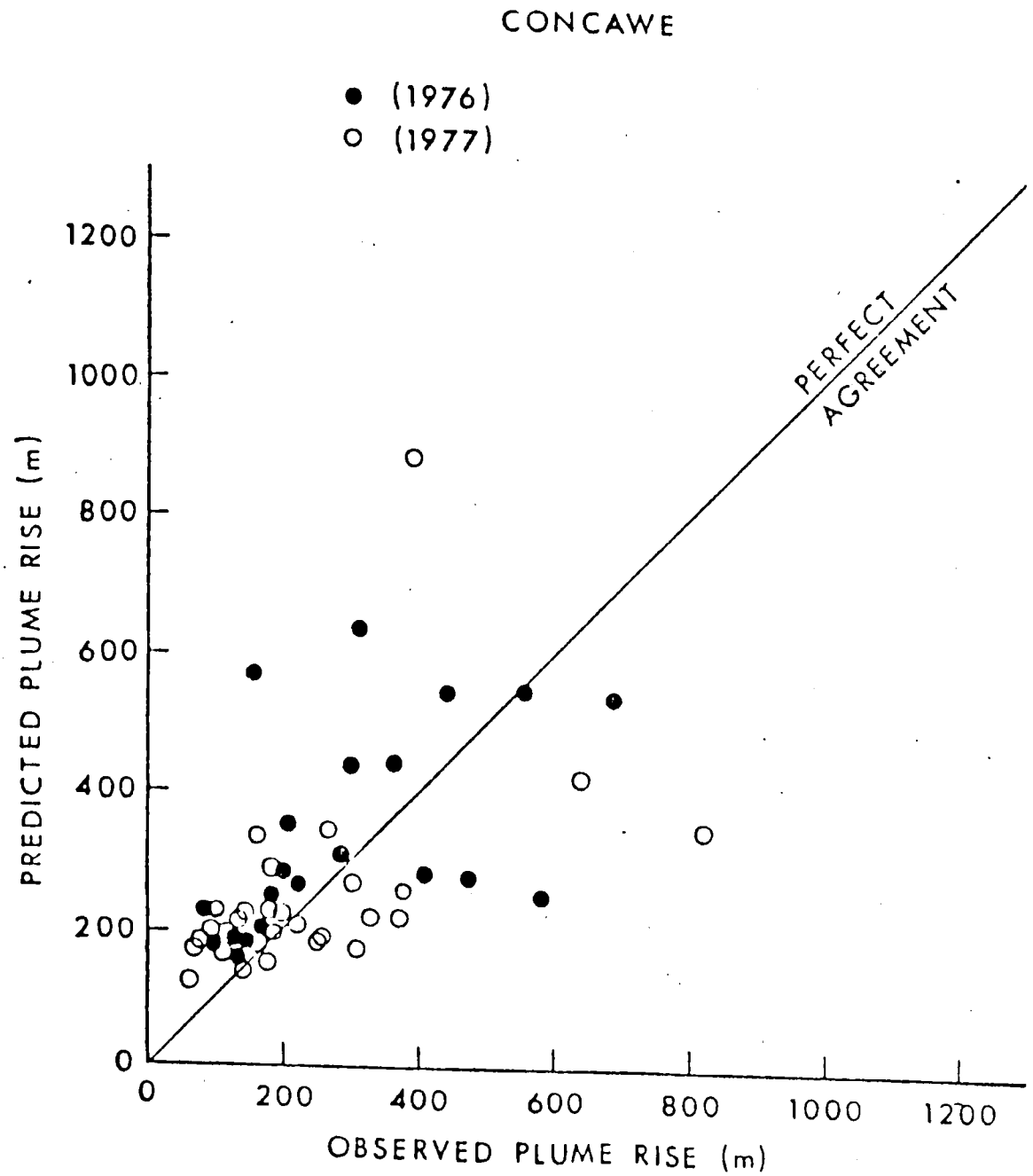


Figure 9. Comparison of predicted versus observed plume rise using Concawe's model. Solid line represents perfect agreement.

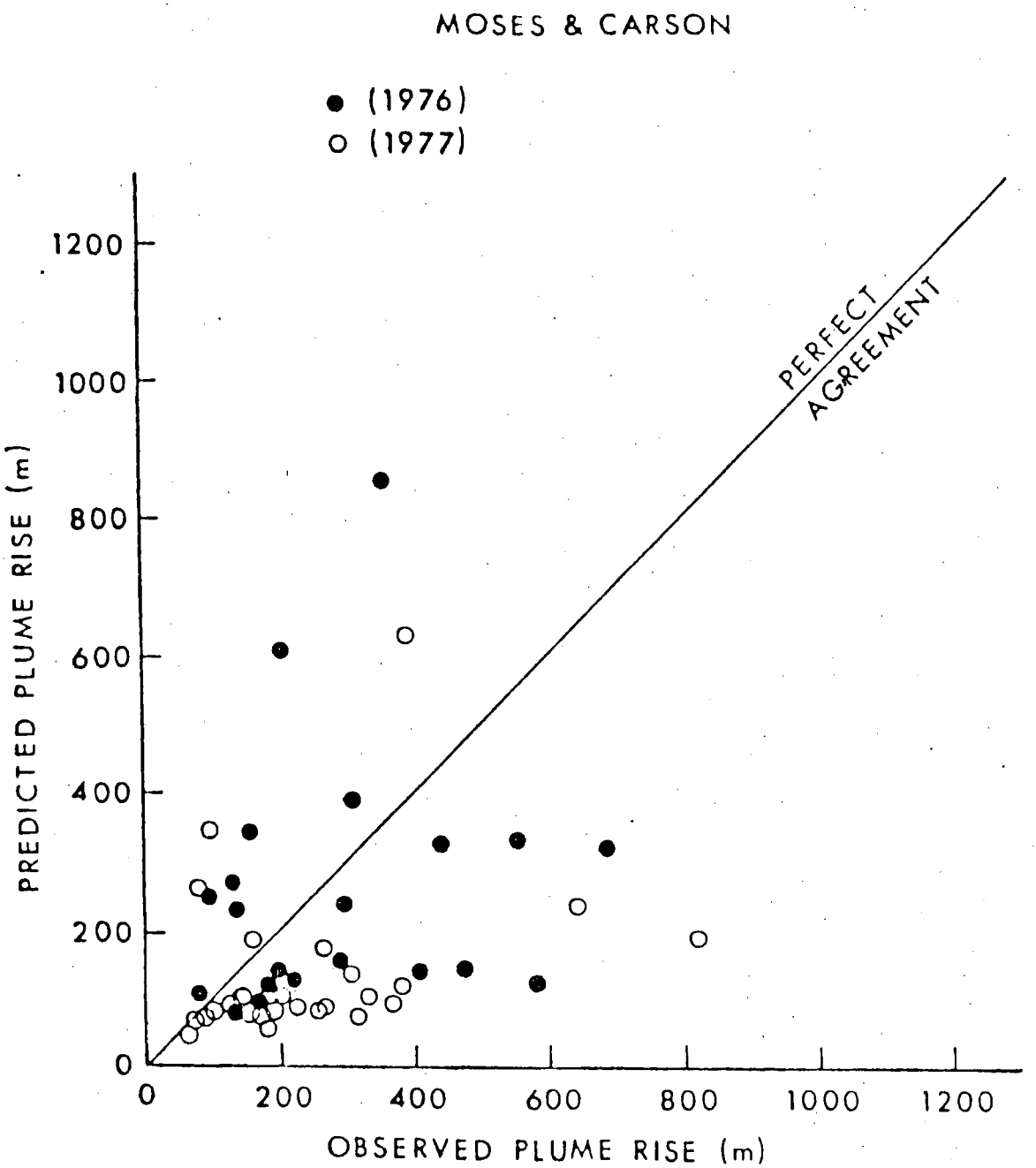


Figure 10. Comparison of predicted versus observed plume rise using Moses and Carson's model. Solid line represents perfect agreement.

TABLE 1 Ratios of observed to predicted plume rise for different wind speed ranges.

Wind Speed Range ($m \cdot s^{-1}$)	Ratios of Observed to Predicted Plume Rise					
	Briggs	TVA 1971	TVA 1972	Holland	Concawe	Moses & Carson
U<2	1.46	0.59	1.8	0.66	0.77	1.28
2<U<3	1.19	0.43	1.42	0.73	0.76	0.83
3<U<4	1.33	0.74	1.09	1.09	0.98	1.74
4<U<6	1.15	1.01	1.14	1.15	0.97	2.03
6<U	1.3	0.82	2.36	0.95	0.71	0.78

Lakes are also often associated with the development of inversion layers and lake breezes during the summer. In summer, as the air moves above the relatively cooler water surface, it is cooled and an inversion layer develops. As the air moves inland, heating from the relatively warmer land below erodes the cooler inversion layer. This convective over-turning motion causes the pollutants trapped in this layer to fumigate to the ground. To avoid potentially dangerous errors in the design and planning of cities, the intensity and frequency of occurrence of inversion layers should be determined.

On clear sunny days the land heats more rapidly than the adjacent lake water. This difference in heating creates a pressure difference which in turn puts the air in motion as shown by the arrows in Figure 11. Lake breezes, when they are present, modify the direction of the plume and may bring polluted air to an unexpected location. At a low level, the plume can move inland while at a high level, its direction can be reversed to flow out over the lake.

In deep valleys, under low geostrophic wind and clear sky conditions, local anabatic winds can be generated that move from the shady side (A) in Figure 12 to the sunny side (B) of a valley. A plume released at (A) will rise to higher levels than a plume released at (B). Thus higher ground level concentrations of pollutants are expected at the (B) side of the valley.

Another example is illustrated in Figure 13 which shows the change in the air flow caused by the presence of a hill. The upwind effect is only noticeable close to the obstruction while on the downwind side the flow is modified for a considerable distance. Here, wind speed and direction, as well as turbulent structure, will be changed. These modifications are illustrated by the different behaviour of the three smoke plumes near the hill. For an upwind stack (A) the plume rises to the top of the hill. The flow over the hill creates a low pressure area which in turn causes the formation of a turbulent wake at the lee side of the hill. Here, the plume will downwash (B),

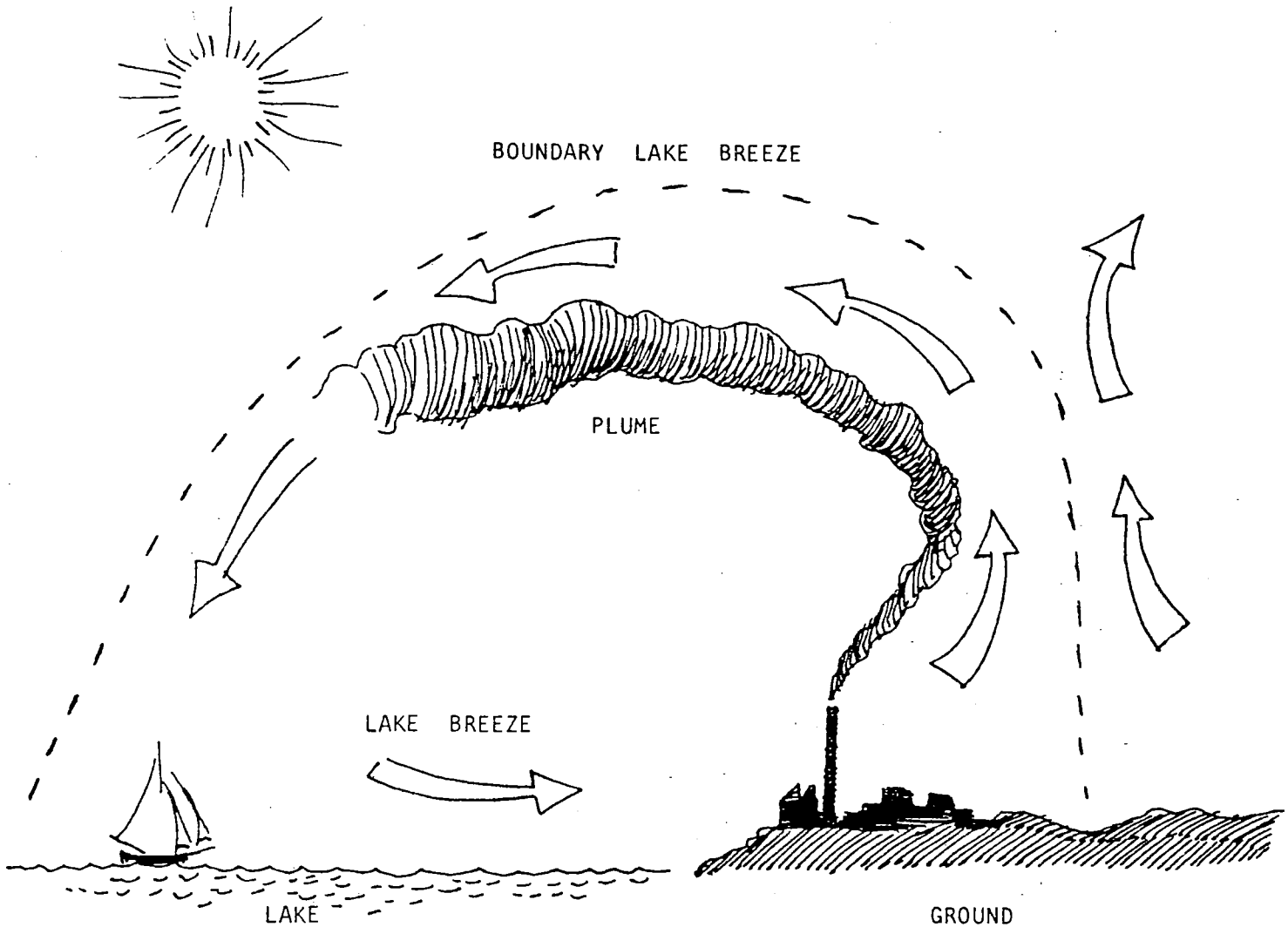


Figure 11. Vertical structure of a lake breeze. Note the change in the plume direction as it rises because of the lake breeze.

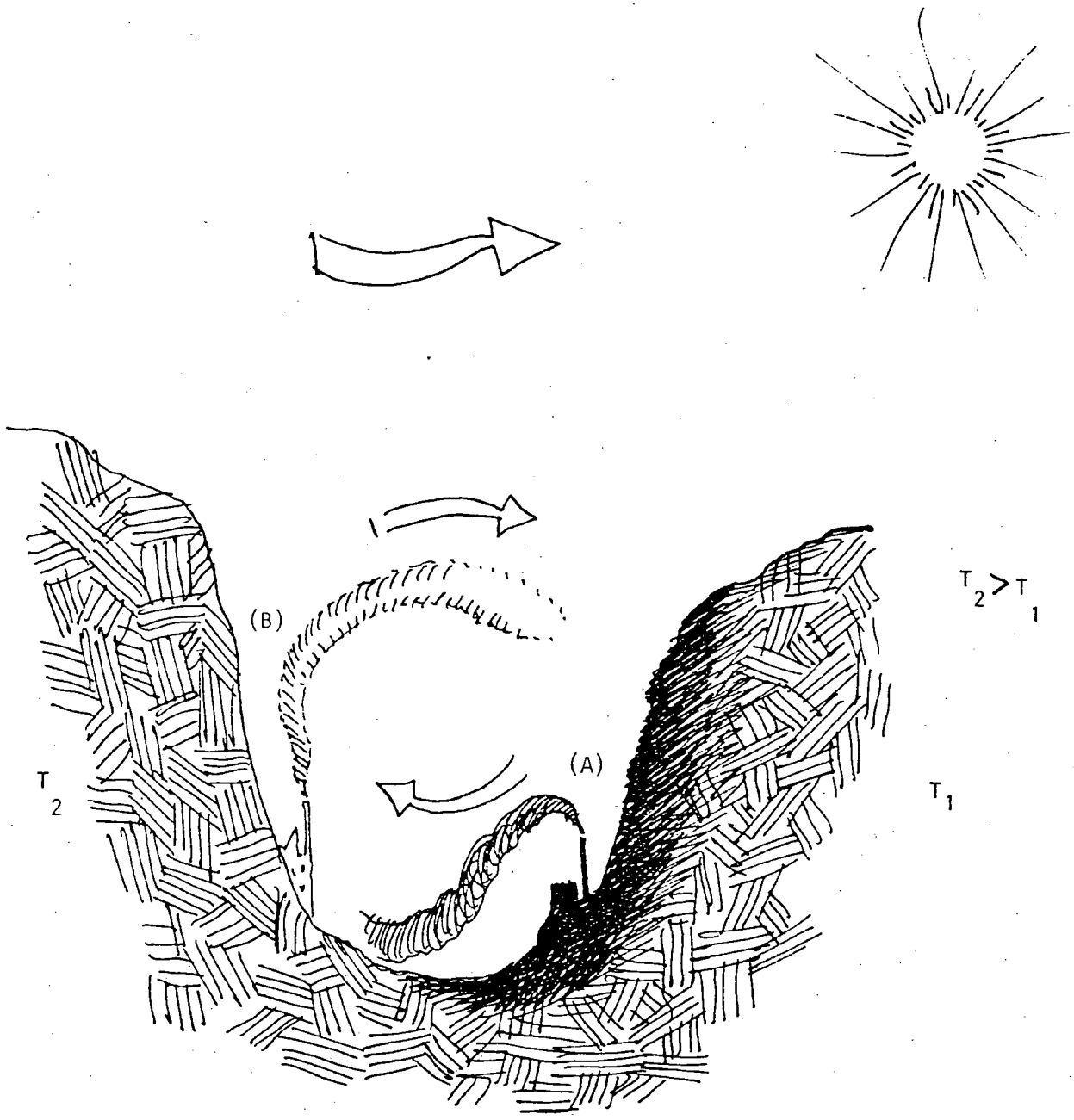


Figure 12. Vertical cross-section of a valley showing air circulation by arrows. High ground level concentration of pollutants is expected at the upwind side.

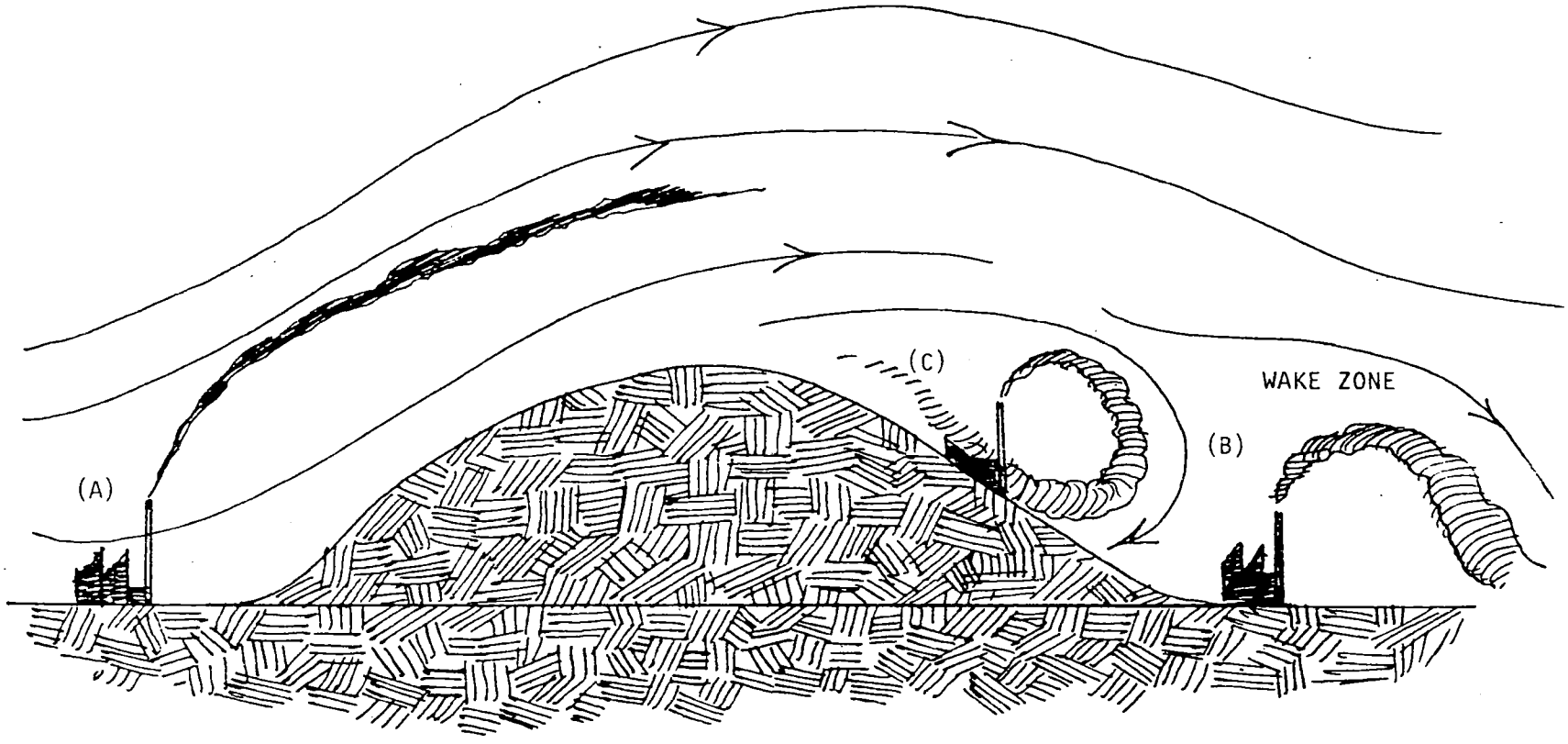


Figure 13. Wake structure of a hill in a two-dimensional flow.

or may rise uphill (C) depending on the source location.

Airflow is also affected by buildings which change the roughness height. Figure 14 shows a theoretical pattern of air flow as it moves over city buildings. The flow is from the lake to the city. Over the lake the flow is relatively smooth but as it passes the edge of the urban area, it is disturbed and becomes highly turbulent. Light winds are accelerated and strong winds are decelerated. The roughness effect may be felt up to 2.5 times the height of the tall buildings, and may cover the whole region below the broken line (Figure 14). A plume emitted at the upwind edge of a city will travel towards the city as a coherent plume with little dilution. As it intersects the urban turbulent boundary layer, eddies of different sizes diffuse the plume of pollution towards the surface causing unfavourable air quality conditions (Hirt, Shenfeld, Lee, Whaley and Djurfors, 1971).

CONCLUDING REMARKS

Many aspects of the plume behaviour have been discussed in this lecture to illustrate the important role that meteorology and topography play.

The rise of the plumefrom stacks in a cold environment is complicated by frequent occurrence of inversion layers in the morning.

Briggs' formulas appear to predict the rise better than others reported here. The correlation, however, between the observed and predicted values is low.

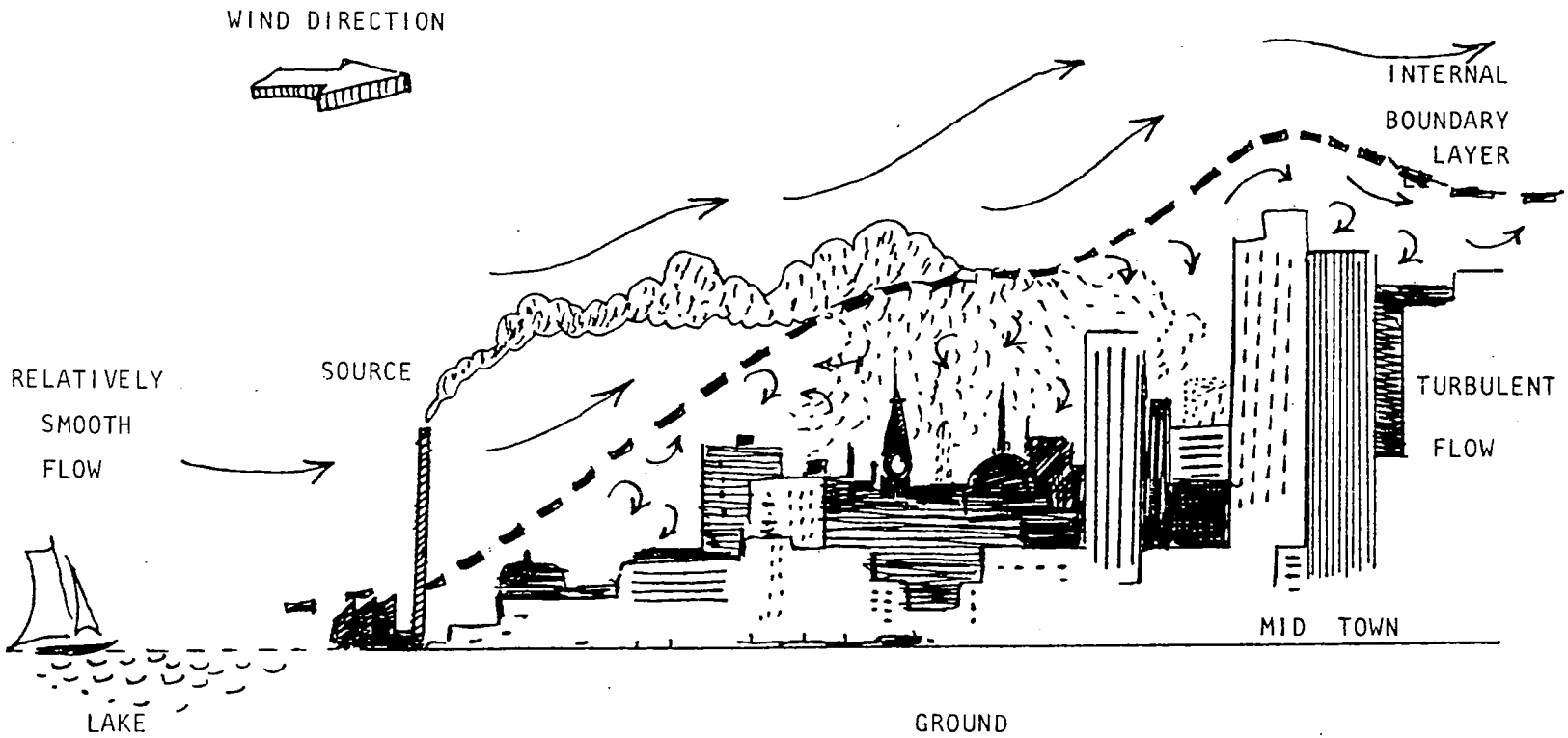


Figure 14. Effect of urban roughness on the flow. The flow is from the lake to the city.

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APPENDIX 1

VARIABLES	DEFINITION
D,d	Internal stack diameter at exit (m)
F	Buoyancy flux parameter ($m^4.s^{-3}$)
H	Effective stack height (m)
h	Stack height (m)
Δh	Plume Rise (m)
M	Stack gas mass emission rate (kg/s)
Q_p	Point source pollutant emission rate (kg/s)
Q	Heat emission rate (MW, cal/s)
R_o	Internal stack radius (m)
R	Plume radius
T_s	Stack gas temperature at exit (K)
V	Volume flux rate of stack gases (m^3/s)
V_s	Stack gas exit velocity (m/s)
ρ_s	Stack gas density (kg/m^3)
ΔT	Stack gas temperature excess (K)
	$\Delta T = T_s - T$ where T is air temperature
w	Plume vertical speed (m/Δ)

METEOROLOGICAL PARAMETERS

c_p	Specific heat of dry air at constant pressure = 1004.64 $J.kg^{-1}.K^{-1}$
g	Acceleration due to gravity 9.8 ms^{-2}
P	Air pressure (kPa)
p_o	Reference pressure = 100 kPa
R	Gas constant for dry air = 287.04 $J.kg^{-10}.K^{-1}$
S	Stability parameter (s^{-2})
T	Air temperature ^{o}(K)
U	Wind speed (m/s)
γ_d	Dry adiabatic lapse rate = 9.76^{o}K/km
θ	Plume potential temperature (^{o}K)
θ_e	Air potential temperature (^{o}K)

θ	Potential temperature (K)
ρ	Air density (kg/m^3)
σ_y	Horizontal (crosswind) dispersion parameter (m)
σ_z	Vertical dispersion parameter (m)

INDEPENDENT VARIABLES:

x	Downwind distance (m)
y	Crosswind distance (m)
z	Vertical coordinate (m)
t	Time (s)

OTHERS:

g	Acceleration due to gravity = 9.806 m/s^2
x	Downwind distance at which turbulence begins to dominate entrainment (m)
x_f	Downwind distance defined by Briggs as $x_f = \frac{\pi U}{\sqrt{S}}$ = downwind distance at which a plume in a stable atmosphere reaches its maximum height.
C	Pollutant concentration ($\mu g/m^3$, PPM)

BASIC LAWS AND RELATIONS

$$\frac{R}{C_p} = \frac{2}{7} \approx 0.2857$$

$$\gamma_x = \frac{g}{C_p}$$

$$\theta = T \left(\frac{p_o}{p}\right)^{R/C_p}$$ [Definition of θ]

$$s = \frac{g}{T} \frac{\partial \theta}{\partial z}$$ [Definition of s]

$$F = \frac{g}{\pi \rho C_p T_s} Q$$ [Definition of F]

$$= \frac{g V_S d^2}{4} \frac{T_S - T}{T_S}$$

$$Q = \pi R_o^2 \rho c_p V_s \Delta T$$ [Definition of Q]

$$\rho = \frac{p}{RT}$$ [Gas law for dry air]

$$\rho_S = \frac{p}{R T_S}$$ [Gas law for stack gas (mainly air)]

$$\frac{\partial p}{\partial z} = - \rho g$$ [Hydrostatic approximation]

$$F_M = \frac{V_S^2 d^2}{4} \frac{T}{T_S}$$ [Momentum flux]

CONVERSION FACTORS

ENGLISH UNIT	=	CONVERSION FACTOR	=	SI UNIT
ft, ft/s		0.3048		m, m/s
mph		0.44704		m/s
knots		0.51481		m/s
ft^3/s		2.8317×10^{-2}		m/s
^oF		$\frac{5}{9}(^oF-32) + 273.15$		K
lb		0.4536		kg
lb/hr		1.2600×10^{-4}		kg/s
kcal/s		4.18684×10^{-3}		MW

RELATIONS BETWEEN UNITS

$Pa = N/m^2$ $\qquad \frac{Pa}{J} = m^{-3}$

$W = J/s = N.m/s$

$1000 \text{ mbar} = 100 \text{ k Pa} = 10^5 \text{ Pa} \simeq 1 \text{ atm}$

STABILITY CLASSIFICATIONS & DISPERSION COEFFICIENTS

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INTRODUCTION

Air pollution concentration patterns are controlled by atmospheric diffusion, a process that depends on the state of the atmospheric turbulence at any location and time;however, atmospheric turbulence is difficult and expensive to measure directly. Consequently, it is useful to be able to describe the boundary-layer turbulence in terms of routine measurements of the mean values (30 to 60 minute averages) of meteorological quantities and their vertical gradients, principally the average temperature, the horizontal wind and the vertical gradients of wind and temperature. The theory of the relation between these quantities and the turbulence has been worked out in considerable detail for the lower part of the boundary layer and is, by and large, quite successful.

However, the relationship between these quantities and atmospheric diffusion is much less well understood. Therefore, it has been found necessary to develop empirically based, more-or-less qualitative, turbulence typing schemes in order to handle practical atmospheric diffusion problems.

STABILITY

1. DEFINITION

In its simplest terms, the stability of the atmosphere is its tendency to resist or enhance vertical motion, or alternatively to suppress or augment existing turbulence. Stability is related to both wind shear and temperature structure in the vertical.

2. PASQUILL'S METHOD

A system of classifying stability on an hourly basis for research in air pollution is based on work accomplished by

Dr. F. Pasquill (1961) of the British Meteorological office. Stability near the ground is dependent primarily upon net radiation and wind speed. Without the influence of clouds, insolation (incoming radiation) during the day is dependent upon solar altitude, which is a function of time of day and time of year. When clouds exist, their cover and thickness decrease incoming and outgoing radiation. In Dr. Pasquill's system insolation is estimated by solar altitude and modified for existing conditions of total cloud cover and cloud ceiling height. At night, estimates of outgoing radiation are made by considering cloud cover. Pasquill presented information on the lateral spreading (θ) and the vertical spreading (h) of diffusing plumes as functions of six atmospheric stability classes designated A to F. These were arranged so that class A corresponds to extremely unstable conditions and class F to stable conditions. The available stability category is chosen by reference to a table (TABLE 1) relating these categories to observed wind speed, cloud cover and insolation conditions.

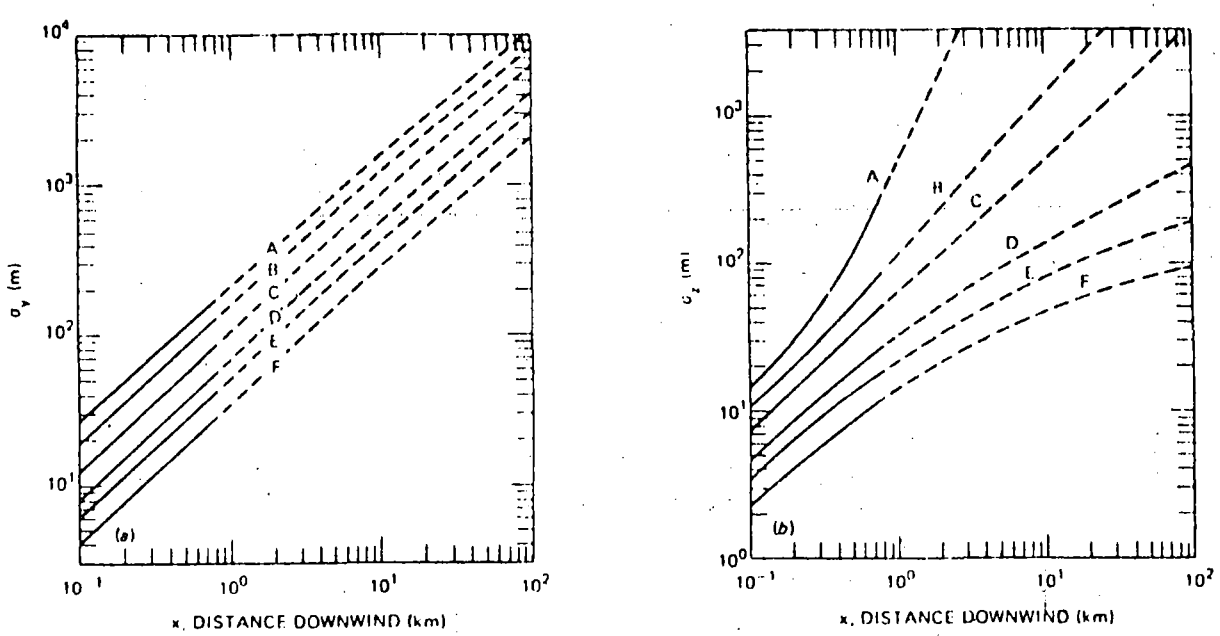
Dr. F. Gifford (1961) converted the plume spreading data into families of curves of standard deviations, σ_y and σ_z, of the plume concentration distribution. This was done partly because the standard deviation is a very commonly used statistic and partly to emphasize that the method could readily be used with the Gaussian plume formula. The graphs of σ_y and σ_z are referred to as the Pasquill-Gifford curves (Figure 1), where A = extremely unstable;B = moderately unstable;C = slightly unstable;D = neutral;E = slightly stable and F = moderately stable.

TABLE 1. KEY TO STABILITY CATEGORIES

Surface Wind Speed (at 10 m), m sec^{-1}	DAY INCOMING SOLAR RADIATION Strong	Moderate	Slight	NIGHT Thinly $\geq$4/8	Overcast or Low Cloud	$\leq$3/8 Cloud
<2	A	A-B	B			
2-3	A-B	B	C		E	F
3-5	B	B-C	C		D	E
5-6	C	C-D	D		D	D
>6	C	D	D		D	D

The neutral class, D, should be assumed for overcast conditions during day or night.

Figure 1. Pasquill-Gifford Curves.



"Strong" insolation corresponds to sunny midday conditions in mid-summer in England and "slight" insolation to similar conditions mid-winter. "Night" refers to the period one hour before sunset to one hour after dawn.

Pasquill recommends the above, as tentative estimates of vertical and horizontal spread in open country, for use in the absence of wind fluctuation data.

3. TURNER'S METHOD

Dr. D.B. Turner (1961) introduced a version of Pasquill's scheme in which the incoming solar radiation is classified in terms of elevation angle, cloud amount and cloud height. This stability classification system has been made completely objective so that an electronic computer can be used to compute stability classes. The stability classes proposed by Turner are as follows: A = extremely unstable; B = unstable; C = slightly unstable; D = neutral; E = slightly stable; F = stable and G = extremely stable.

Table 2 gives the stability class as a function of wind speed and net radiation. The net radiation index ranges from 4, highest positive net radiation (directed toward the ground), to -2, highest negative net radiation (directed away from the earth). Instability occurs with high positive net radiation and low wind speed, stability with high negative net radiation and light winds, and neutral conditions with cloudy skies and/or high wind speeds.

The net radiation index, used with wind speed to obtain stability class, is determined by the following procedure:

TABLE 2. STABILITY CLASS AS A FUNCTION OF NET RADIATION AND WIND SPEED

WIND SPEED (KNOTS)	NET RADIATION INDEX 4	3	2	1	0	-1	-2
0, 1	A	A	B	C	D	F	G
2, 3	A	B	B	C	D	F	G
4, 5	A	B	B	C	D	F	G
6	B	B	C	D	D	E	F
7	B	B	C	D	D	D	E
8, 9	B	C	C	D	D	D	E
10	C	C	C	D	D	D	E
11	C	C	D	D	D	D	D
≥12	C	D	D	D	D	D	D

(1) If the total cloud cover is 10/10 and the ceiling is less than 7000 feet, use net radiation index equal to 0 (whether day or night).

(2) For night time (night is defined as the period from one hour before sunset to one hour after sunrise):

a. If total cloud cover $\leq$4/10, use net radiation index equal to -2.

b. If total cloud cover >4/10, use net radiation index equal to -1.

(3) For day time:

a. Determine the insolation class number as a function of solar altitude from Table 3.

b. If total cloud cover $\leq$5/10, use the net radiation index in Table 2 corresponding to the insolation class number.

c. If cloud cover >5/10, modify the insolation class number by following these six steps:

(1) Ceiling <7000 ft., subtract 2.

(2) Ceiling $\geq$7000 ft. but <16000 ft., subtract 1.

(3) Total cloud cover equal 10/10, subtract 1. (This will only apply to ceilings $\geq$7000 ft. since cases with 10/10 coverage below 7000 ft. are considered in item 1 above).

(4) If insolation class number has not been modified by steps (1), (2), or (3) above, assume modified class number equal to insolation class number.

(5) If modified insolation class number is less than 1, let it equal 1.

(6) Use the net radiation index in Table 2 corresponding to the modified insolation class number.

TABLE 3. INSOLATION AS A FUNCTION OF SOLAR ALTITUDE

SOLAR ALTITUDE (a)	INSOLATION	INSOLATION CLASS NUMBER
$60^{\circ} < a$	Strong	4
$35^{\circ} < a \leq 60$	Moderate	3
$15^{\circ} < a \leq 35$	Slight	2
$a \leq 15^{\circ}$	Weak	1

4. STAR ANALYSIS

Martin and Tikvart (1968) developed a computer programme called STAR (STability ARray) which generated frequencies and percentage frequencies of wind direction by speed class for each stability category. This system has been found to give a good first approximation of the stability (instability) of the atmosphere where no low-level temperature and wind profile data exist.

The STAR system has at least one characteristic worth noting. By definition, stable conditions can occur only at night and unstable conditions only in the day. With the neutral category being the only one that can occur during both day and night, the original programme has been modified to produce a Day/Night STAR. This particular version breaks the neutral category into Neutral/Day and Neutral/Night and is used directly by the Climatological Dispersion Model (CDM).

When a STAR output is examined, one notices a seasonal shift toward higher frequencies of more unstable categories from winter to summer. This is attributable in part to the increasing length of daylight and the increased solar elevation. The stable category, on the other hand, reaches a maximum in the autumn due partly to non-cloudy nights and light winds.

One must also be careful when using the STAR Summary as the yearly averages vary from year to year. Using a one-year STAR can lead to conclusions which may not be generally representative of other periods. In order to obtain generally

representative data, it is recommended that STAR'S be based on at least five years of data.

5. INTER-COMPARISONS OF STAR AND MEASURED STABILITY

There have been some recent studies which have tried to assess how well the STAR programme matches the observed stability. Luna and Church (1972) compared turbulence intensity and stability ratio measurements made on an instrumented tower against the STAR output derived from weather observations. They concluded that, although, on the average, predictions using the mean values were fairly well correlated, there was such a large scatter in individual values that any value of turbulence intensity could belong to any stability class. They also demonstrated that the neutral category D, did not seem to represent zero lapse rate.

Other researchers demonstrated that the STAR stability classes had a strong dependence on surface roughness and that the system gives unreliable stability information because of local geographical and climatological conditions.

Portelli (1976a) compared the STAR stability to classifications determined directly from vertical temperature profile data taken during several field studies carried out at various locations across Canada. Portelli concluded that the predicted and observed stability class frequency distributions are not very similar. The neutral class D was found to be substantially over-predicted while the stable cases were generally under-predicted. Unstable cases were over-predicted, under-predicted or correctly-predicted depending on the location. In his comparison of 528 observations only 21.6% of the cases were correctly predicted by the STAR programme.

Portelli (1976b) compared STAR predictions and vertical temperature profiles taken at plume-level. He concluded that the STAR programme performs better in predicting plume-level stability than in low-level stability. The correct stability was predicted in over 60% of the cases studied.

WIND DIRECTION STANDARD DEVIATION AND VERTICAL TEMPERATURE STRUCTURE

1. INTRODUCTION

Cramer (1957) suggested a method of classifying turbulence for the purpose of diffusion estimation based on the standard deviation of the wind measured by bi-directional wind vanes. By correlating observations of σ_A and σ_E, the azimuth and elevation angle standard deviations, for a range of stabilities, with simultaneously measured horizontal plume spreading he set up a table of correspondences between σ_A and σ_E values and the plume standard deviations.

On the basis of this and other related studies, Slade (1968) proposed correspondences between σ_A values and the Pasquill-Gifford curves. These are outlined in Table 4 with relationships using the average vertical temperature structure ($\Delta T/\Delta Z$) as given by USAEC (1972). These methods are satisfactory at any particular site, however, the relationship of turbulence type to lapse rate ($\Delta T/\Delta Z$) has generally proven to be too variable from site to site to be useful.

TABLE 4. RELATIONS FOR WIND-DIRECTION AND VERTICAL-TEMPERATURE STRUCTURE DERIVED STABILITIES

PASQUILL	SLADE σ_A (DEGREES)	USAEC $\Delta T/\Delta Z$ ($^oC/100m$)	BNL
A	25	$\Delta T/\Delta Z \leq -1.9$	B_2
B	20	$-1.9 < \Delta T/\Delta Z \leq -1.7$	B_1
C	15	$-1.7 < \Delta T/\Delta Z \leq -1.5$	B_1
D	10	$-1.5 < \Delta T/\Delta Z \leq -0.5$	C
E	5	$-0.5 < \Delta T/\Delta Z \leq 1.5$	-
F	2.5	$1.5 < \Delta T/\Delta Z \leq 4.0$	D
G	-	$4.0 < \Delta T/\Delta Z$	-

2. BROOKHAVEN NATIONAL LABORATORY METHOD

The BNL turbulence typing scheme is based on the range of fluctuations of the horizontal wind-direction trace. The BNL types have the following definitions:

B_2: Fluctuations recorded over 1-hour ranging from 40 to 90°

B_1: Fluctuations similar to B_2 but confined to 15 and 45° limits.

C : Fluctuations greater than 15° distinguished by the unbroken solid core of the trace.

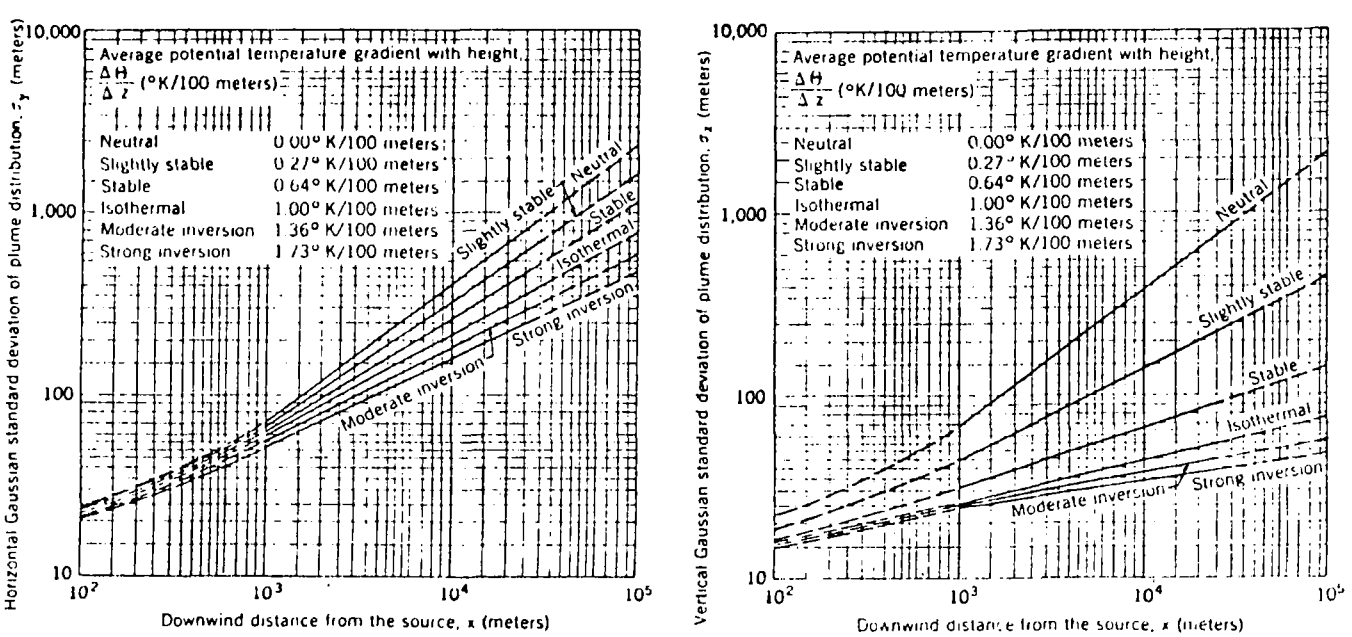
D : The trace approximates a line;short-term fluctuation do not exceed 15°.

These categories are site specific and apply strictly to conditions equivalent to those of the test (height = 108 m; averaging time = 1 hour; non-buoyant plume). The relationship between the BNL scheme and the Pasquill categories is given in Table 4. The BNL dispersion curves are used in the ASME Guide (1973).

3. TENNESSEE VALLEY AUTHORITY METHOD

Carpenter et al (1971) summarized 20 years of TVA experience with the measurement of concentration patterns and related values of meteorological parameters. Stack heights ranged from 75 to 250 m and all the plumes studied were buoyant. TVA used a six-category typing scheme, ranging from neutral to strong inversion, based on lapse rate and illustrated in Figure 2.

Figure 2 - TVA Curves



BRIGGS INTERPOLATION FORMULAS

In the typing schemes discussed so far, the data bases used to derive them were measured for differenct applied problems. If one inter-compares the various schemes, there are major disagreements. This situation has been discussed and resolved to the extent possible by Briggs (1974). He noted the following characteristics.

- The PG curves were developed primarily with the aid of diffusion measurements made to a distance of 800 m using a non-buoyant gas released near the surface.
- The BNL curves reflect non-buoyant plume dispersion from an elevated (108m) source. Ground level concentrations were obtained out to several kilometres.
- TVA data reflects greater effective heights (from 150 to 600 m or more) and downwind distances of up to tens of kilometres.

This led Briggs to propose a series of interpolation formulas for σ-curves that would have the following properties:

- They would agree with the PG curves in the range 100 m<x<10000 m, except that the curves of σ_z for A and B stability would approximate the BNL values for σ_z>100 m.
- The TVA, BNL and PG curves agree reasonably well (except for A and B conditions noted above) at about 10 km.
- beyond 10 km TVA curves are less steeply inclined.

Briggs recommends his curves for up to 10 km and Gifford (1976) suggests that they could be extended to 20 or 30 km. The Briggs values are summarized in Table 5 and are intended primarily for use in calculating ground-level concentrations for plumes from elevated stack sources.

TABLE 5. FORMULAS RECOMMENDED BY BRIGGS for $\sigma_y(x)$ and $\sigma_z(x)$; $10^2 \leq x \leq 10^4$ m,

OPEN-COUNTRY CONDITIONS

PASQUILL TYPE	σ_y (m)	σ_z (m)
A	$0.22x(1+0.0001x)^{-\frac{1}{2}}$	$0.20x$
B	$0.16x(1+0.0001x)^{-\frac{1}{2}}$	$0.12x$
C	$0.11x(1+0.0001x)^{-\frac{1}{2}}$	$0.08x(1+0.0002x)^{-\frac{1}{2}}$
D	$0.08x(1+0.0001x)^{-\frac{1}{2}}$	$0.06x(1+0.0015x)^{-\frac{1}{2}}$
E	$0.06x(1+0.0001x)^{-\frac{1}{2}}$	$0.03x(1+0.0003x)^{-1}$
F	$0.04x(1+0.0001x)^{-\frac{1}{2}}$	$0.016x(1+0.0003x)^{-1}$

BOUNDARY LAYER TURBULENCE CRITERIA

1. INTRODUCTION

Various studies have shown that the qualitative stability categories like those of Pasquill correspond generally to direct measurements of boundary layer turbulence intensity but that there is considerable scatter. Variations in surface roughness and thermal properties from site to site, not specifically allowed for in the simple schemes proposed, also have an effect on the vertical dispersion.

This situation has led various workers to examine the relationships between stability types and theoretical criteria of boundary layer turbulence that specifically account for these factors.

2. RICHARDSON NUMBER

One can use the Richardson number (R_i) which is defined by:

$$R_i = \frac{g}{T} \frac{\partial\theta/\partial z}{(\partial u/\partial z)^2}$$

where g = gravitational acceleration

T = absolute temperature

θ = potential temperature

$\partial\theta/\partial z$ = minus the vertical gradient of potential temperature lapse rate

$\partial u/\partial z$ = wind shear

This number contains information of the required kind but it varies with height in the steady-state boundary layer. For flow over a fairly smooth surface (short grass) the order of magnitude relationships between R_i and Pasquill type are given in Table 6. A more easily measured bulk Richardson number B was defined by Lettau and Davidson (1957) as follows:

$$B = \frac{g}{T} \frac{\partial\theta/\partial z}{u^2} z^2$$

TABLE 6. RELATIONSHIPS BETWEEN PASQUILL TYPE AND TURBULENCE CRITERIA R_i AND L.

PASQUILL TYPE	R_i (at 2m)	L,m
A	-1.0 → -0.7	-2 → -3
B	-0.5 → -0.4	-4 → -5
C	-0.17 → 0.13	-12 → -15
D	0	∞
D	0.03 → 0.05	35 → 75
F	0.05 → 0.11	8 → 35

3. MONIN-OBUKHOV LENGTH

A more useful index of the state of the boundary layer turbulence is the Monin-Obukhov length:

$$L = -(u_*^3 \, C_p \rho T)/kgH$$

where C_p = specific heat at constant pressure

ρ = density

k = Von Karman's constant

H = vertical heat flux

u_* = friction velocity as determined from the surface shear stress

$= (\tau/\rho)^{\frac{1}{2}}$

Pasquill and Smith (1970), using detailed atmospheric diffusion experiments, provided estimates of the relationships with the Pasquill categories for flow over a fairly smoth surface. These are presented in Figure 3.

Golder (1972) derived the relationship shown in Figure 3.

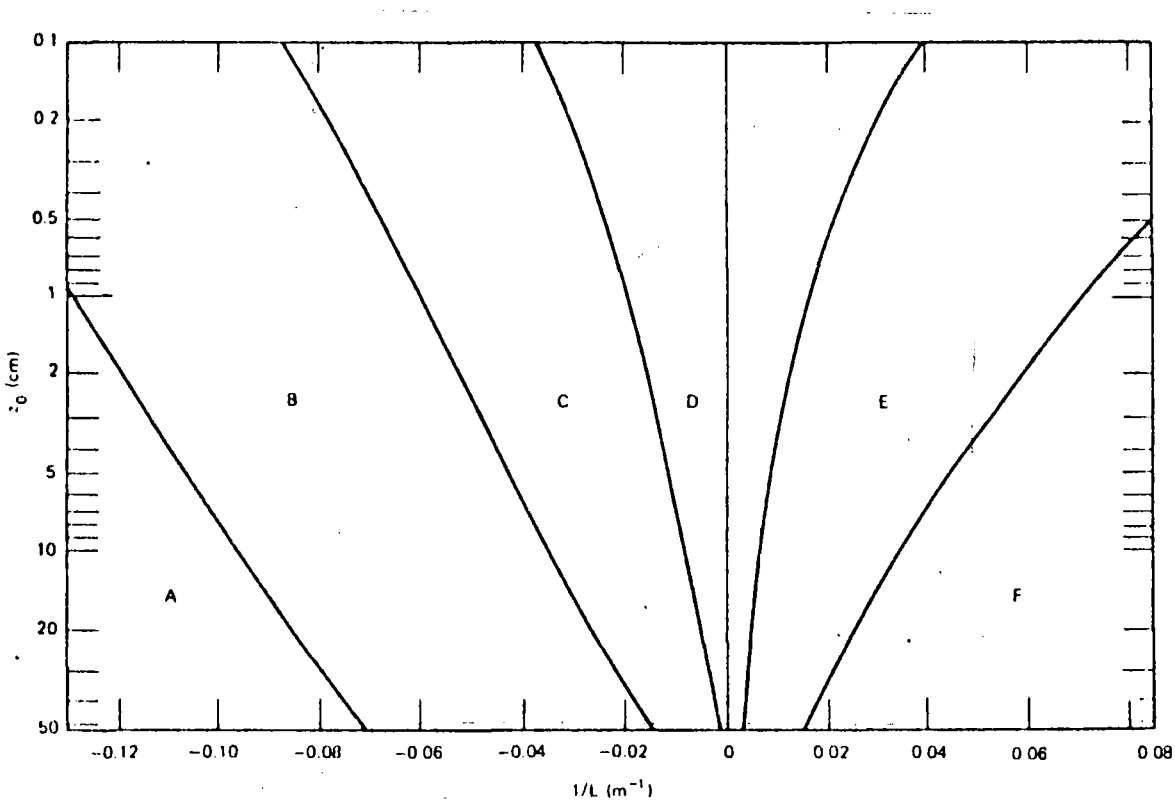


Figure 3. Curves by Golder (1972) showing Pasquill's turbulence types as a function of the Monin-Obukhov stability length and the aerodynamic roughness length (Z_o).

PRACTICALITIES

1. ESTIMATING INSOLATION*

The Smithsonian Meteorological Tables (List, 1951) are re-

* taken from Lavdas 1976

quired to estimate insolation which is an input required for determining stability class. Explaining the solar altitude and azimuth graphs is difficult; in fact, more than a few meteorologists have found the graphs incomprehensible at first glance. This is because solar elevation is a function of latitude, longtitude, time zone, clock changes, etc.

The easiest way for a layman to determine solar elevation angle is by observing his own shadow. The shadow length on level ground is dependent on solar angle - which determines potential insolation.

Table 7 shows for a 6 foot man the relationship between solar elevation angle, shadow length, and insolation class. For heights other than 6 feet, simply multiply the height by the cotangents given in column 2 to produce a modified column 3.

TABLE 7. Relationship between solar elevation angle, shadow length, and insolation class.

Solar Elevation Angle	Cotangent (to be multiplied by height of object casting shadow)	Shadow length of 6 foot object on level ground (Feet)	Insolation Class
$>60^{o}$	<0.5774	<3½	Strong
35° -60°	0.5774-1.428	3½-8½	Moderate
15° -35°	1.428-3.732	8½-22½	Slight
$<15^{o}$	>3.732	>22½	Weak

The layman using this table has an accurate and easy method for, estimating insolation. But -- like the sundial, this tool is useless when clouds obscure the sun. Fortunately in the Pasquill Scheme of determining stability class, solar angle is irrelevant if the sky is overcast with clouds thick enough to eliminate shadows. The only problem occurs with broken cloud when the sun refuses to show itself and a shadow

length measurement is needed.

This problem can be avoided by making the estimate in advance. One should pick a clear day within one week of the required time at the exact time of day that is of interest. This estimate will result in a solar elevation angle error of no more than 3°. This procedure can also be used when one is estimating long duration emissions that will occur over a range of solar elevation angles.

2. WIND-DIRECTION STANDARD DEVIATION($\sigma_{A \text{ or } E}$)

There is a simple convenient rule of thumb relating the wind-direction standard deviation (σ_A or σ_E) for a sample of the order of an hour and the range of wind-direction fluctuations over the period. This is:

$$\sigma_A = (A_{max} - A_{min})/6$$

where A is the azimuth angle measured in degrees.

Thus σ_A can easily be found directly from the trace of A(t), that is, the chart record of a wind vane, by inspection.

3. TIME AVERAGING

Since motions in the atmosphere are not constant with time the concentrations of pollutants are also variable with time. Mean concentrations of pollutants measured over different time periods are not directly comparible. This is due primarily to the fluctuation of the horizontal wind direction. If sampling is conducted downwind from a source a short sample of 3 to 5 minutes duration will yield a certain concentration but as the sampling interval is increased to say an hour, the mean concentration will decrease due to short periods of time when the wind is not blowing directly from the source to the receptor (even though the mean wind throughout the sampling interval is from source to receptor).

An empirical mathematical relationship has been proposed for relating peak to one-hour mean concentrations:

$$\frac{P}{M} = \left[\frac{60}{t}\right]^r$$

where P = peak concentration (t-minute average)

M = one hour mean concentration

t = time in minutes

r = 0.65 for very unstable (class A)

= 0.52 unstable (class B,C)

= 0.35 neutral (class D)

= 0.00 stable (class E,F)

This relationship is shown graphically in Figure 4.

Figure 4. Relationship of PEAK Short Term Centreline Concentrations to ONE HOUR MEAN Concentrations.

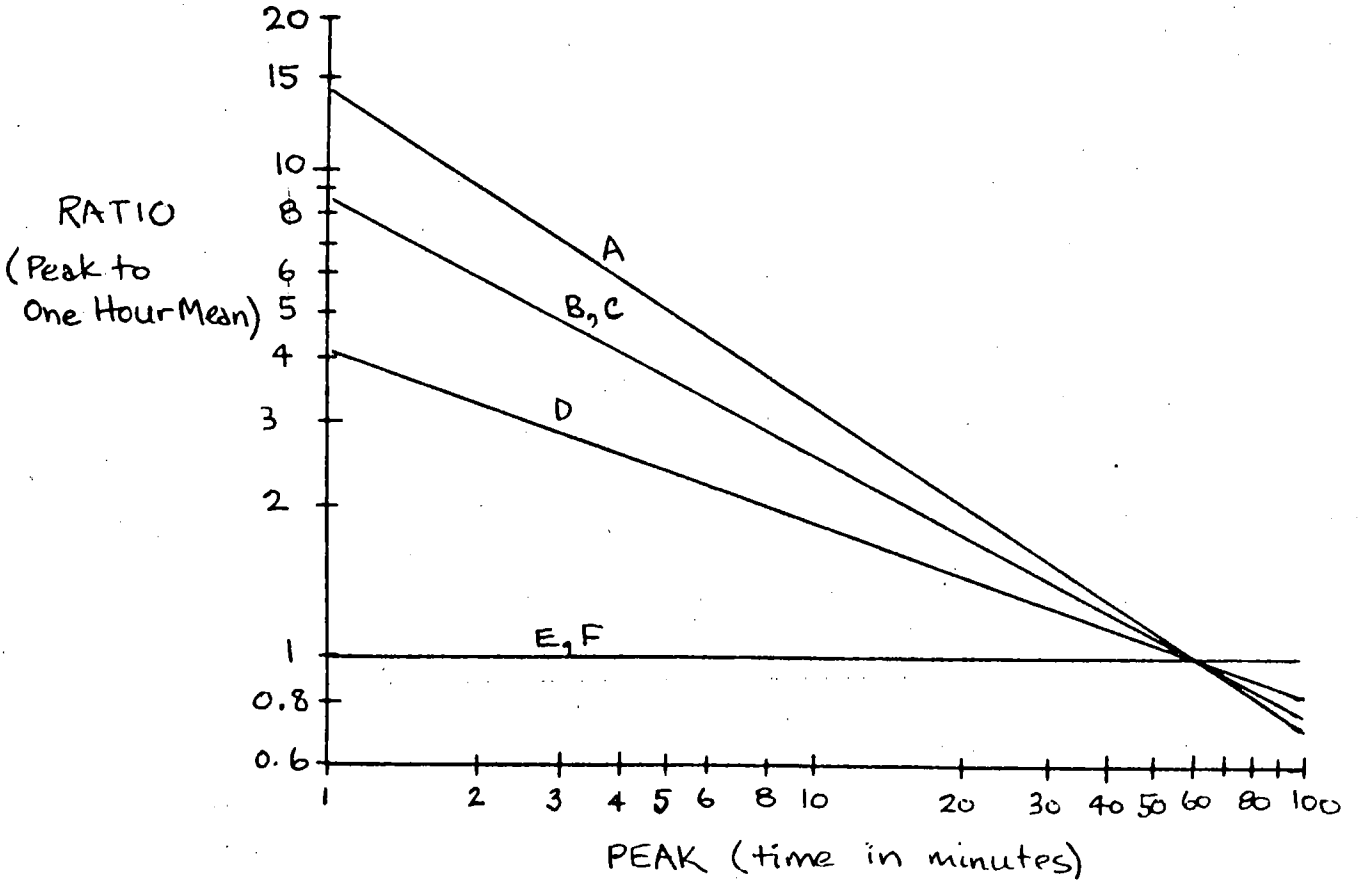


Figure 4 shows that under neutral conditions the peak 3 minute concentration over an hour is about 2.8 times the hourly mean. Under very unstable conditions when the vertical direction of the wind is also rapidly changing the peak 3 minute concentration can be expected to be about 7 times the hourly concentration.

The question also arises about what the concentration average will most likely be over periods longer than one hour up to 24 hours, given a one-hourly average. While there is no substitute for measured data, the following may be used as a first approximation:

Averaging Time	Correction
1 hour	1.0
3 hours	0.94
8 hours	0.8
24 hours	0.37

4. DIFFUSION IN CITIES

Diffusion over cities is enhanced, compared with that over open country, not only because the surface roughness is greatly increased but also because of the great heat capacity of cities. The net increase in turbulence intensity is evidently 40% when compared to open country.

Based on a series of observations over St. Louis, Briggs proposed the urban σ_y and σ_z values shown in Table 8.

TABLE 8. FORMULAS RECOMMENDED BY BRIGGS FOR $\sigma_y(x)$ and $\sigma_z(x)$; $10^2 \leq x \leq 10^4$ m, URBAN CONDITIONS

PASQUILL TYPE	σ_y, m	σ_z, m
A-B	$0.32x(1+0.0004x)^{-\frac{1}{2}}$	$0.24x(1+0.001x)^{\frac{1}{2}}$
C	$0.22x(1+0.0004x)^{-\frac{1}{2}}$	$0.20x$
D	$0.16x(1+0.0004x)^{-\frac{1}{2}}$	$0.14x(1+0.0003x)^{-\frac{1}{2}}$
E-F	$0.11x(1+0.0004x)^{-\frac{1}{2}}$	$0.08x(1+0.0015x)^{-\frac{1}{2}}$

5. ACCURACY

Estimates of pollution concentration based on turbulence

typing methods may be accurate to within 20% for long-term averages, given good quality emissions and meteorological data, but may exceed a factor of 2 for short-term values.

6. DIRECT MEASUREMENT OF DISPERSION COEFFICIENTS

In most studies, the important differentiation is between stable and unstable cases. Improved dispersion estimates can usually be obtained by measuring data at the site to be evaluated. Proper equipment at source height would include an anemometer to obtain the mean wind speed, temperature instruments at two heights to determine the stability and a bivane to obtain the standard deviation of the vertical and horizontal angles of the 3-dimensional wind. From these instruments, the diffusion parameters can be approximated by the equations*;

STABLE

$$\sigma_y = 0.15\ \sigma_A\ x^{.71}$$

$$\sigma_z = 0.15\ \sigma_E\ x^{.71}$$

UNSTABLE AND NEUTRAL

$$\sigma_y = 0.045\ \sigma_A\ x^{.86}$$

$$\sigma_z = 0.045\ \sigma_E\ x^{.86}$$

where σ_y (degrees) = standard deviation of the azimuth angle at source height.

σ_E (degrees) = standard deviation of the elevation angle at source height.

x = downwind distance in metres

7. WHERE DO THESE SCHEMES NOT APPLY?

The foregoing schemes are all specifically restricted to distances up to 10 km or several tens of kilometres at most because the experimental data base of these essentially qualita-

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* valid for uncomplicated surroundings and distances less than 10 km.

tive and empirical schemes is very scanty for downwind distances beyond a few kilometres.

For longer distances, the underlying surface type may change, introducing changes in roughness and thermal conditions. Vertical diffusion ultimately extends through the entire boundary layer, which is usually topped by a stable layer. This limits σ_z to the so-called "mixing depth". Use of the mixing depth as a limit of σ_z is recommended in nearly all typing schemes.

Flows over cities, flows over large bodies of water, wake flows (flows behind obstacles) and very light wind stable flows (clear, calm nights) all lie outside the limits of Pasquill's basic system and were specifically excluded by him.

I have included a discussion of flow over cities and a good review paper on the other topics has been written by Gifford (1976).

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DISCUSSION/COMMENTS

R. GILBERT: I would like to know if any attempt has been made to extend the Turner typing scheme to take the albedo into consideration? For example, here in our latitude when we want to use a Turner typing scheme in winter with the presence of snow cover, you just can't use it. The albedo is a important factor in that case. Is there anybody who has worked on that matter?

J.W.S. YOUNG: Not that I know of.

R.V. PORTELLI: This has been given some consideration in Canada but no work has been done here. Apparently some individuals in the U.S. are looking into this and as yet, they haven't come up with any information on it. This is to be incorporated, hopefully, into the STAR scheme which is used very widely in the States.

WET AND DRY DEPOSITION OF POLLUTANTS

L.A. BARRIE
Atmospheric Dispersion Division

1. INTRODUCTION

The residence time of a pollutant in the atmosphere is determined by the rate at which it is removed by precipitation, by direct up-take at the earth's surface (dry deposition) and by chemical transformation. Wet and dry removal processes are dealt with in this paper. They represent a very broad range of physical and chemical processes on spatial scales from 10^{-7}m (e.g. cloud drop/particle interactions) to 10^{6}m(e.g. scavenging efficiency of warm frontal storm systems). More than a brief introduction is therefore not possible within the scope of this workshop presentation.

I will outline the subject matter and introduce some of the basic concepts, terminology and methods commonly used in tackling problems related to dry and wet removal. If the reader wishes to obtain greater detail, he is referred to excellent reviews by Hales (1978), Garland (1978) and Slinn (1979) as well as to two published conference proceedings entitled "Precipitation Scavenging"- 1970 and 1974.

2. WET REMOVAL

There are two types of wet removal processes, in-cloud scavenging (or rainout) and below-cloud scavenging (or washout). In-cloud scavenging begins within a cloud when pollutants are incorporated into cloud water (or ice) and ends as they are removed by precipitation falling to the earth. The pollutant may be injected directly into the cloud by a tall stack or may enter via the updrafts at cloud base. A particle or gas is incorporated into cloud water by several microphysical processes:

1) condensation of water on hygroscopic pollutant particles to form cloud drops (involves particles > .2 micrometer diameter).

(2) brownian diffusion of particles to cloud drops or ice particles (particles <0.2 micrometers diameter).

(3) interception/impaction of particles by cloud drops, raindrops or ice particles falling at different terminal velocities (particles >1 micrometer diameter)

(4) Diffusion- and thermo-phoresis and electrical attraction.

(5) dissolution of gases in cloud water.

Particle capture by hydrometeors is irreversible. On the other hand, gaseous uptake is reversible unless the gas is converted in solution by chemical reaction to a non-volatile product (e.g. sulphur dioxide to sulphate). Under equilibrium conditions, which are established within milliseconds in a cloud, the concentration of dissolved gas in cloudwater κ is directly proportional to the gas phase concentration χ. This relationship is known as Henry's Law:

$$\chi = H\kappa \qquad (1)$$

H is Henry's constant. Its inverse H^{-1} is a measure of the gas's solubility. Values of H for various atmospheric trace gases of interest are listed in Table 1. Some gases (e.g. SO_2, CO_2, H_2S, NH_3) listed are reactive in water. They not only physically dissolve but also dissociate to form ions. Their solubility in water is generally pH - dependent and higher than indicated by Henry's constant which represents the physically dissolved fraction only. The particular case of SO_2 is discussed in more detail later.

The bulk of particulate mass entering a cloud is incorporated into cloudwater within a few minutes after condensation. The fraction of a gas that enters the liquid phase depends on its solubility. Not all particulate or gaseous mass entering a precipitating cloud is removed from the atmosphere. A portion of it is reinjected into the air at the evaporating edges. Particulates are removed by a single precipitating cloud at

Table 1.

Values of Henry's Constant H for various gases at 15° C in freshwater (from Slinn et al, 1978).

CCl_3F	5×10^{0}
CO	3.7×10^{1}
CH_4	2.6×10^{1}
C_2H_6	1.7×10^{1}
C_2H_4	6.8×10^{0}
O_3	2.2×10^{0}
N_2O	1.3×10^{0}
CO_2 *	9.3×10^{-1}
SO_2 *	7.9×10^{-3}
NH_3 *	4.7×10^{-4}
Pesticides	
DDT	1.6×10^{-3}
Aldrin	5.3×10^{-4}
Lindane	2.0×10^{-5}
Dieldrin	7.7×10^{-6}

* reactive gases that dissociated in solution. Their solubility is highly pH dependent.

efficiencies falling between 10 and 90%, depending on cloud type. At present the microphysical characteristics of a cloud that controls its scavenging efficiency are difficult and costly to measure. Consequently, not much quantitative information is available on cloud scavenging.

Once precipitation leaves cloud base below-cloud scavenging occurs. Particles are incorporated into raindrops or ice particles and gases are absorbed or desorbed . Below-cloud scavenging is a much simpler process than in-cloud removal since microphysical and dynamical cloud processes are not involved. Nevertheless its complexity is staggering.

The rate at which precipitation removes a substance from the atmosphere is calculated by integrating the mass flux of a pollutant to each hydrometeor (raindrop, hailstone, ice crystal)in a size spectrum of hydrometeors as they fall through the atmosphere.

Pollutant flux to a hydrometeor is determined from its terminal velocity and the experimentally determined collection efficiency E of the hydrometeor for the pollutant. E is the fraction of total pollutant captured from a volume of air swept out by a hydrometeor. It is a function of hydrometeor type and size and, if particles are present, particle size. In addition to the collection efficiency, the following parameters must be known:

1. the size distribution of raindrops or ice crystal in the precipitation.
2. the vertical variation of pollutant concentration. In the case of particles, their size distribution as a function of height, is also required.
3. the chemical composition of the pollutants of interest.

Consider two situations pertinent to plume scavenging; below-cloud scavenging of particles by rain and scavenging of an SO_2 plume by rain. Figure 1 shows a theoretical prediction of E as a function of particle size and rain drop size. The microphysical processes of brownian diffusion, efficient for

small particles, and interception/impaction, efficient for large particles, are represented. Other capture mechanisms such as electrical effects and diffusio- and thermophoresis are considered negligible outside a cloud. For a given raindrop size, E is a minimum for particles between 0.1 and 1 micrometer radius. There exists very little experimental evidence to verify the theoretical predictions in Figure 1. Recent plume washout measurements (Radke et al, 1978) suggest that the minimum in the collection efficiency curve is not nearly as low as theoretically predicted. The best explanation offered is that hygroscopic plume particles in the mid-size ranges grow by condensation as they enter the humid surroundings of a raindrop. They are then more efficiently captured by impaction/interception than if they had retained their initial dimension. Laboratory experiments often use hydrophobic particles and therefore fail to simulate this effect. Note that particles smaller than 3-5 micrometers radius are scavenged more efficiently by small drizzle drops than by larger raindrops.

Very little is known about the particle-scavenging ability of snow. It depends on crystal size, storm type, etc. Theory predicts that an ice crystal's particle collection efficiency varies with particle size in a manner similar to that of rain (Figure 1). That is, a minimum occurs for particles 0.1 - 1 micrometer in radius. In general E is lower for snow crystals than for raindrops of the same diameter.

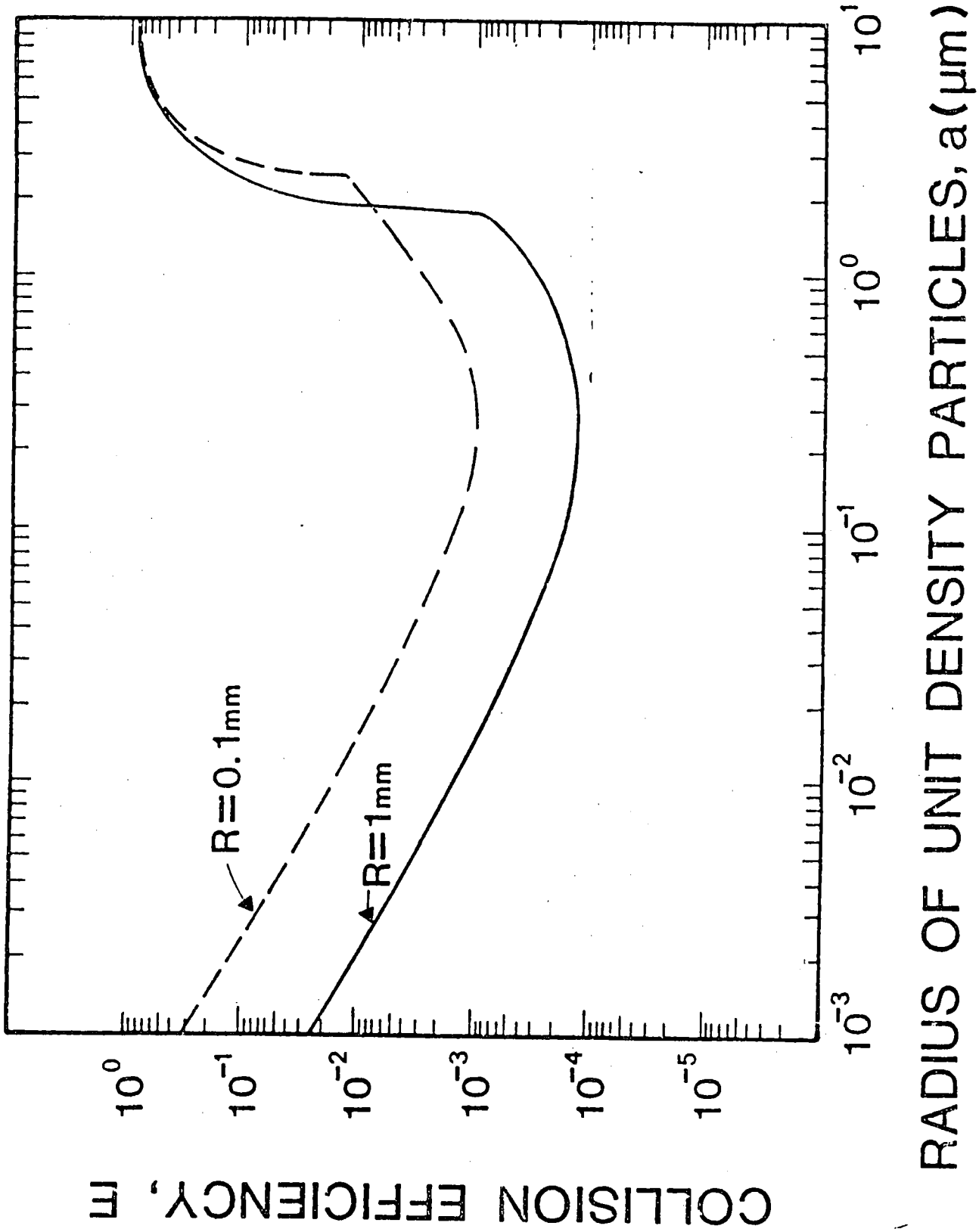
Next, consider washout of sulphur dioxide SO_2 from a plume. As mentioned, SO_2 is typical of a class of gases (CO_2, NO_2, H_2S, NH_3) that not only form physical associations with water (as O_2, N_2 and O_3 do) but also form reactive ionic species.

The reaction scheme for sulphur dioxide system is

AIR-WATER INTERFACE

$$(SO_2)g + (H_2O)_\ell \rightleftarrows (SO_2 \cdot H_2O)_\ell \qquad (2a)$$

Fig. 1 - The collection or collision efficiency E of raindrops of radius R as a function of particle size as predicted by theory (Slinn 1979).



IN WATER

$$SO_2 \cdot H_2O \rightleftarrows HSO_3^- + H^+ \qquad (2b)$$

$$HSO_3^- \rightleftarrows SO_3^= + H^+ \qquad (2c)$$

The predominant form of sulphur dioxide in precipitation (pH 3 - 6) is the bisulphite species HSO_3^-. Results of a plume washout calculation that takes into account the chemistry of SO_2 in solution is illustrated in Figure 2 (Barrie 1978). Note the "washdown" of the plume as a result of the reversible absorption of SO_2 by water. In addition, note that the maximum pollutant concentration in rain collected at the ground occurs in medium sized raindrops about 800 micrometers in diameter.

Parameterization Of Wet Removal Processes For Modelling Purposes

Most approaches to the modelling of wet removal processes are crude ones using parameters derived from commonly available information such as the ground level concentration of a pollutant in air and in precipitation. A dimensionless washout ratio W is frequently used in washout calculations. It is defined as:

$$W = \frac{\kappa}{\chi} \qquad (3)$$

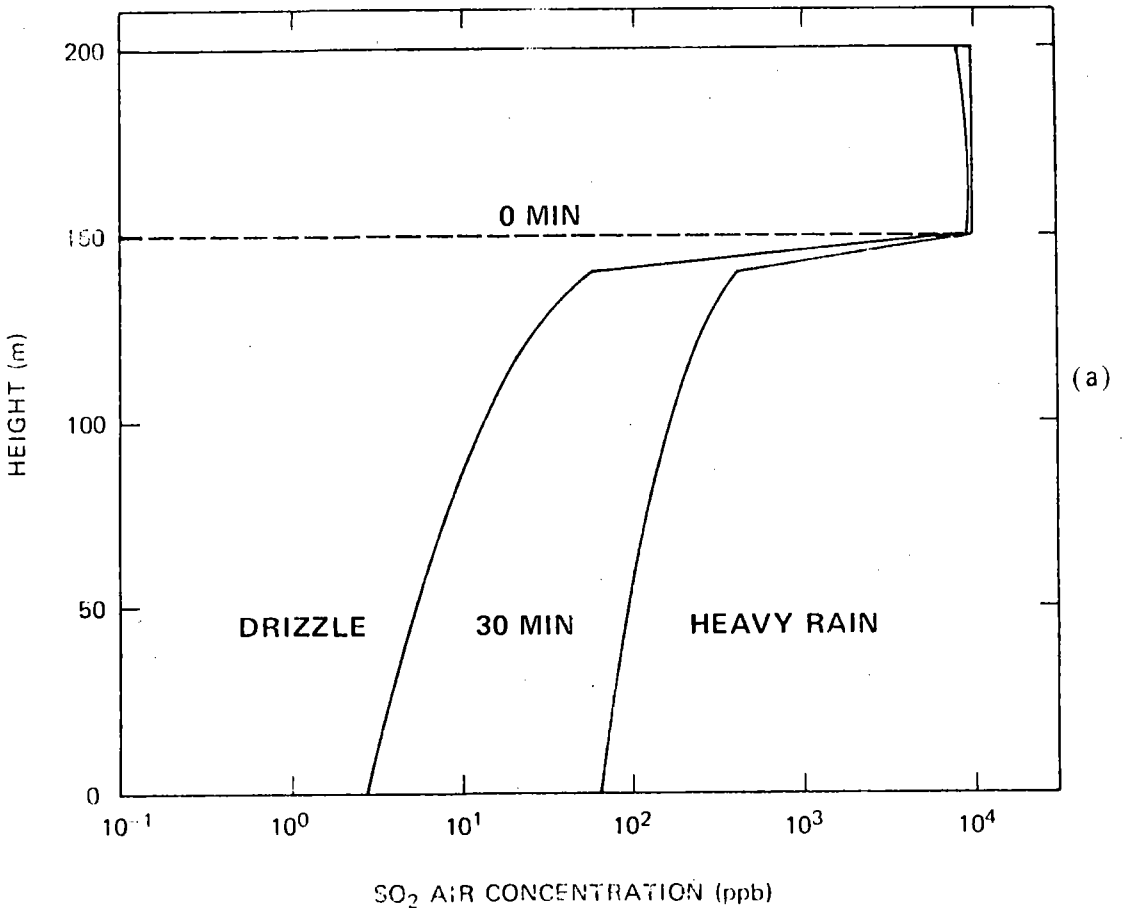
κ and χ are pollutant concentrations in precipitation and in the air being cleansed, respectively.

The downward flux F_p (dimension $ML^{-2}T^{-1}$) of pollutants to the ground in precipitation of intensity I (dimension $L\ T^{-1}$) falling through air containing a pollutant at a concentration χ is given by

$$F_p = IW\chi \qquad (4)$$

Figure 3 shows some data on particulate bomb debris typical of that which initiated interest in washout ratios in the 1960's. A linear relationship exists between ground level air and precipitation concentrations of radioactive isotopes. Table 2 lists measured values of W for various particulate constituents.

Washout ratios can be used for gas scavenging only if



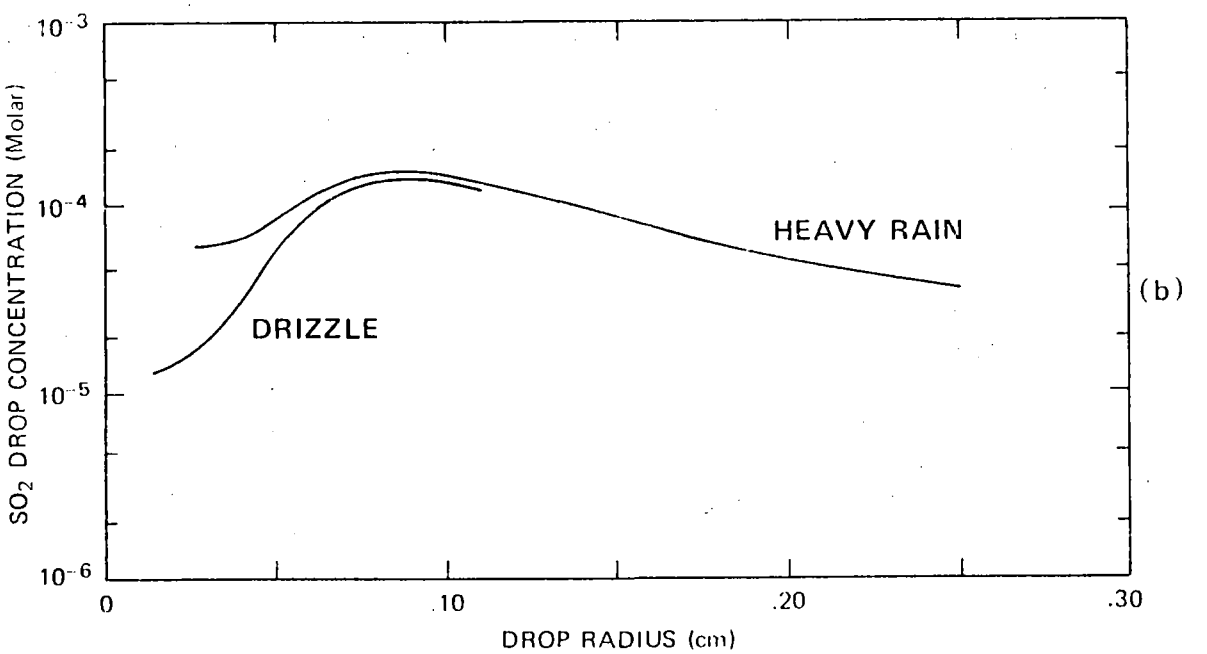


Fig. 2 - (a) The redistribution of an SO_2 plume by reversible below-cloud scavenging by heavy rain and drizzle.
(b) The concentration of SO_2 in rain reaching the ground as a function of raindrop size. (From Barrie, 1978)

Fig. 3 - An example of the correlation between measured concentrations of total fission products in precipitation, K_o, and their concentrations in surface level air (from (Slinn, 1979).

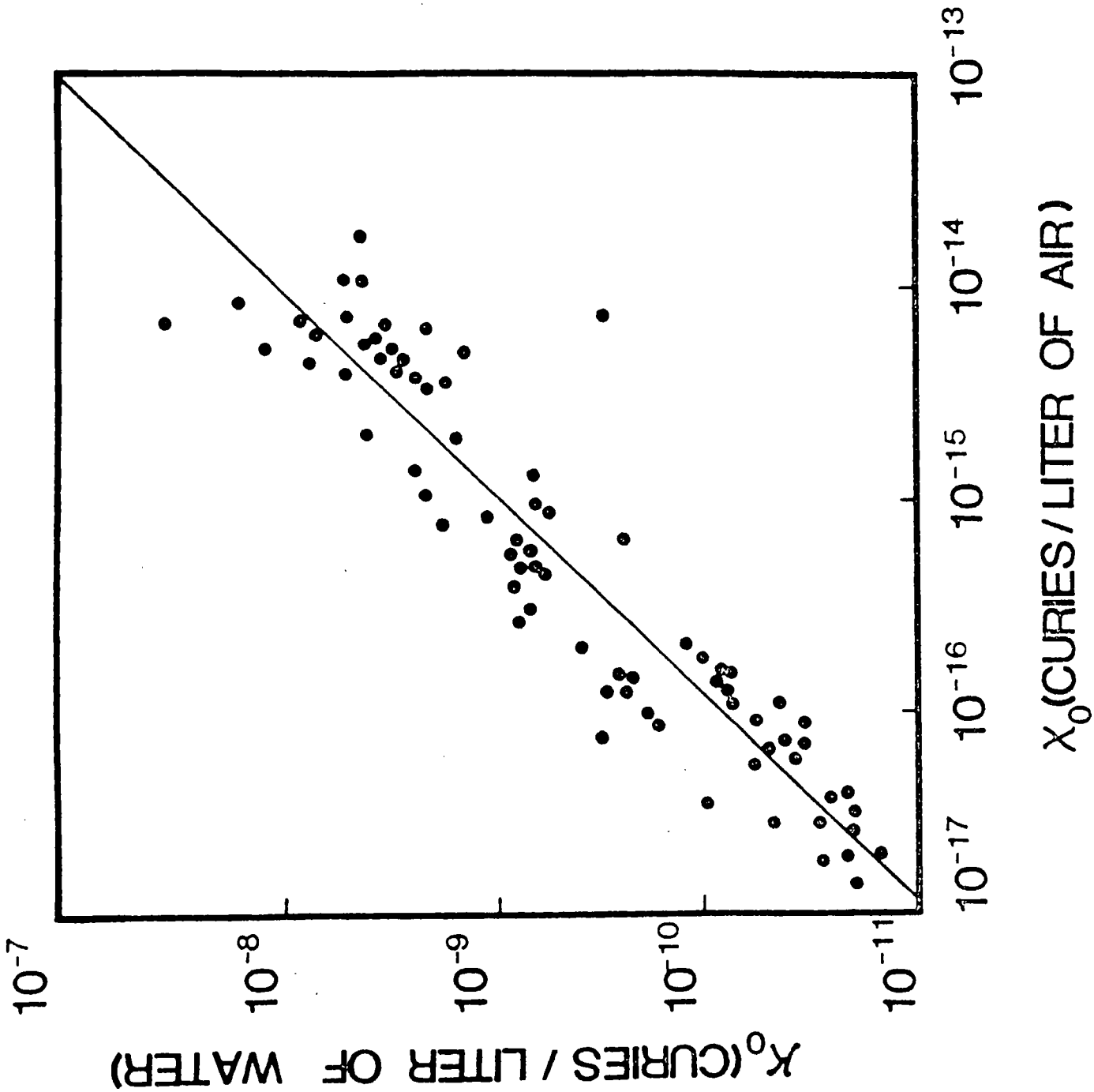


Table 2.

Values of observed washout coefficients W from (Slinn et al, 1978)

Particle Type	$W \times 10^6$	Remarks
Fallout Radionuclides	$1 \pm .03$	1957-65 global average for many radionuclides
Pollen	0.65-3.8	convective storms in Oklahoma
Aerosol Particles Containing:		
Pb	0.063	scavenged by convective storms near St. Louis.
Zn	1.0	
Fe	.21	
Ca	.29	
Mn	.31	
Mg	0.38	
K	0.46	
Pb	0.24	annual average values in the U.K.
Zn	0.40	
Fe	0.23	
Ca	--	
Mn	0.33	
Mg	--	
K	--	

the variations in the vertical distribution of the gas are so gradual that equilibrium between the gas and liquid phases is maintained. Then for unreactive gases W is simply the inverse Henry's-constant H^{-1} (See Table 1). For reactive gases W depends on the acidity of the rain. For example, it can be shown from the solution chemistry of SO_2 (equation 2) that the washout ratio at 10° C is

$$\log_{10} W_{SO_2} = 0.079 + pH \qquad (5)$$

pH is the negative of the log to the base 10 of the hydrogen ion concentration in moles per litre.

Measurement Of Wet Removal

The following guidelines should be observed by anyone doing wet deposition measurements:

1. use wet-only collectors that close between precipitation events thereby excluding dry fallout, bird waste, etc. Bulk collectors such as open garbage cans yield "garbage" data.
2. collection vessels should be constructed of an inert material that does not interact with the pollutant of interest. Avoid using glass for metals and plastic for organics.
3. locate collectors remote from local sources of pollution and wind-blown dust.
4. measure precipitation amount with a standard rain or snow gauge (information available from the Atmospheric Environment Service).
5. precipitation samples should be analyzed as soon after collection as possible. Store at 4°C while waiting for analysis. Preserve trace metals by acidifying the solution to pH 1.5 with ultrapure nitric acid.
6. The representativeness or accuracy of a wet deposition measurement increases with averaging time.

Deposition measurements of rain events are correct within a factor of 2 to 3. A monthly average measurement is more accurate.

The Atmospheric Environment Service is presently operating two wet deposition networks:

(i) The Canadian Network for Sampling Acidic Precipitation (CANSAP)
- 50 stations across Canada (Figure 4)
- monthly precipitation samples analyzed for pH and major ions
- coordinator R. Berry

(ii) The Air and Precipitation Monitoring Network (APN)
- 5 regionally representative stations east of the Manitoba-Ontario border Figure 5.
- event precipitation samples analyzed for pH and major ions.
- air sampling yielding the daily average concentration of SO_2 and particulate major ions in air.
- coordinators L.A. Barrie, H.A. Wiebe.

3. DRY REMOVAL

Dry removal is the direct uptake of an atmospheric trace constituent by the earth's surface. The processes involved in the delivery of a gas or particle to the surface from the free atmosphere and its subsequent interaction with the earth depends on, among other parameters, particle size. (A gas can be regarded as a particle with a very small diameter).

Giant Particles (diameter >20μm)

Wind-blown dust is the main source of these particles. They are transported to the earth's surface from aloft by gravitational sedimentation. Their sedimentation velocity is directly proportional to the square of the particle size (a 100 μm diameter particle settles at 25 cm s^{-1}, a 200 μm particle at 100 cm s^{-1}). Consequently, particles larger than 20-30 μm have a

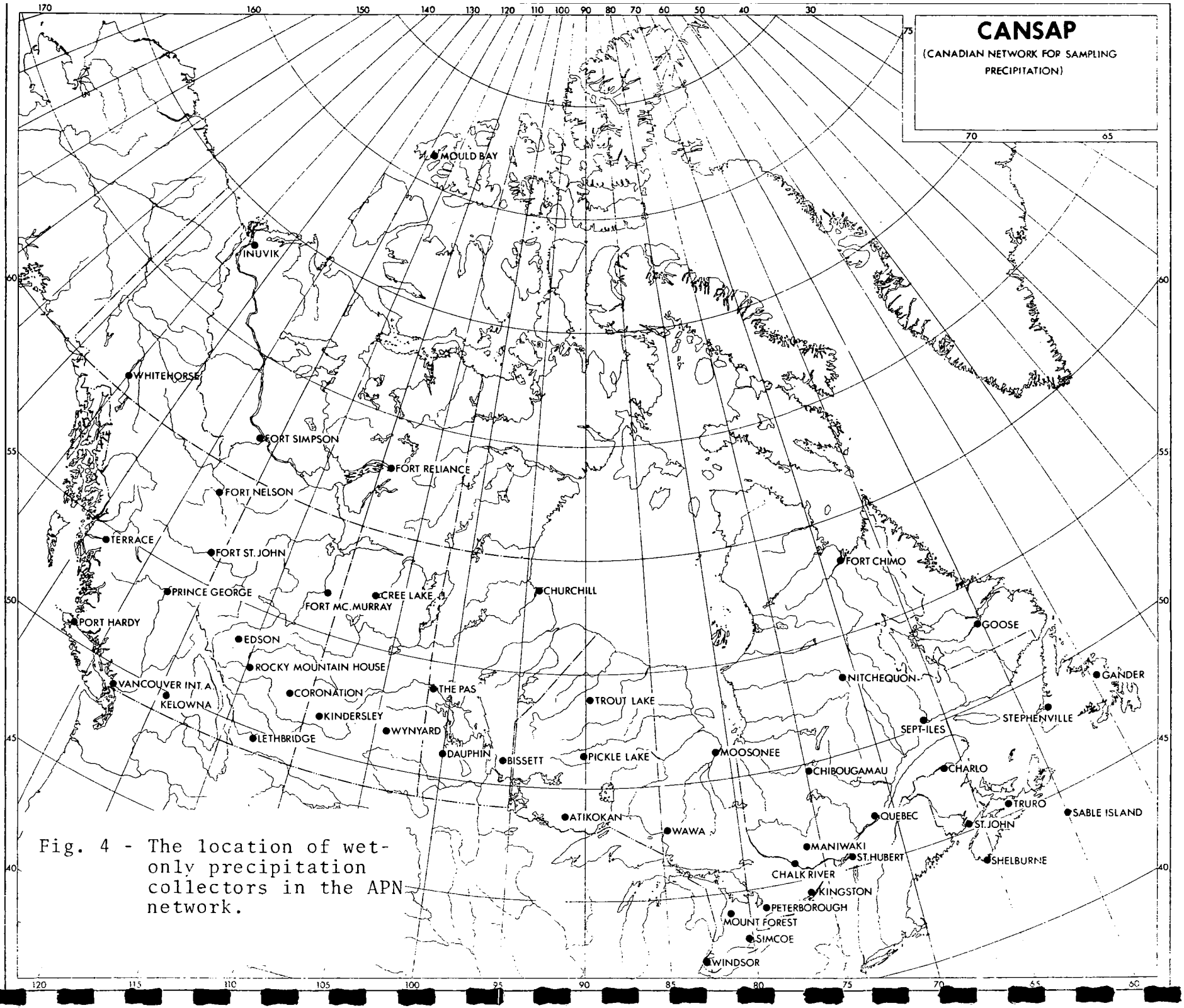
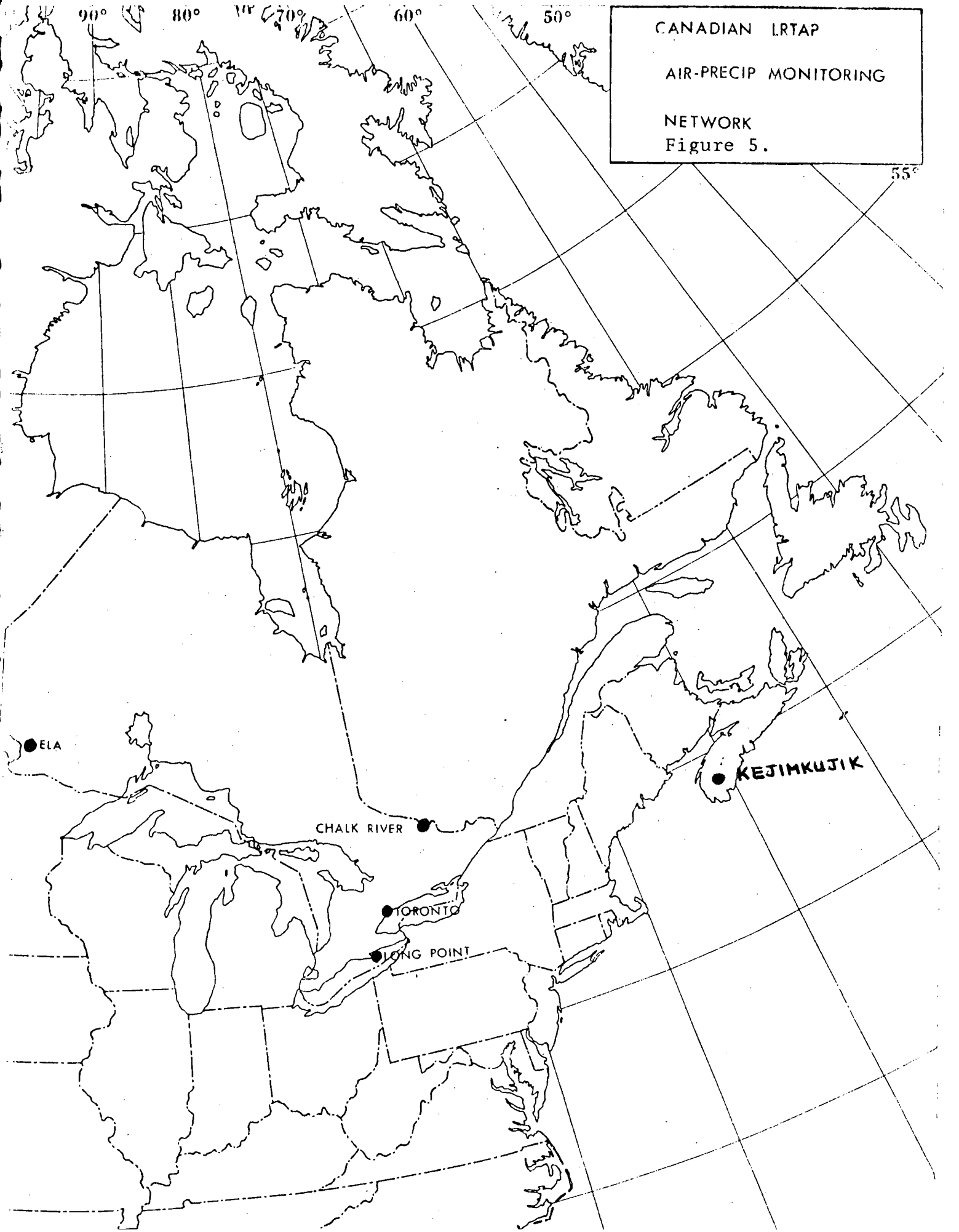


Fig. 4 - The location of wet-only precipitation collectors in the APN network.



CANADIAN LRTAP

AIR-PRECIP MONITORING

NETWORK

Figure 5.

lifetime of no more than a few minutes in the atmosphere.

Large Particles (0.3 - 20 μm diameter)

These particles originate from wind-blown dust, flyash from fossil fuel burning and from the coagulation of smaller particles formed when gases condense. Large particles are transported to the earth's surface by turbulent diffusion. They are then "impacted" onto surfaces by turbulent eddies in the near surface air layer or are "intercepted" by surface elements that project into the air stream (e.g. grass blades). The rate of impaction/interception increases with increasing particle size. A surface's ability to retain large particles impinging upon it depends on its wetness, roughness and surface area, as well as on the chemistry of the particles.

Small Particles (0.001 - 0.3μm diameter)

Small particles originate mainly from condensation of gases and then subsequent coagulation. Transfer from the free atmosphere to the near-surface layer occurs via the same mechanism that brings large particles to the surface, namely turbulent diffusion. But, small particles penetrate the laminar sub-layer near the surface by brownian diffusion or, in the case of gases, by molecular diffusion rather than by impaction/interception. The rate of penetration is inversely proportional to particle diameter raised to the two thirds power.

A surface's ability to collect particles is determined by its wetness, hairiness and surface area as well as by particle-size and chemistry. Particles are collected by physical processes but gases interact chemically with the surface.

The dry deposition flux F of a pollutant to the earth's surface depends upon many variables including: air concentration χ, wind speed, boundary layer stability, particle size and particle(or gas) chemistry. In order to eliminate strong variations in the flux, advantage is taken of the fact that all other factors remaining equal F is linearly proportional to χ. A dry deposition velocity V_d is defined as

$$V_d = \frac{F}{\overline{X}_h} \qquad (6)$$

The subscript "h" on χ_h refers to a certain height above the surface. The concept of deposition velocity is, for modelling purposes, a convenient way of parameterizing dry removal. In practice, dry deposition losses are calculated by multiplying model-predicted, surface-air concentrations by an appropriate deposition velocity.

The inverse of deposition velocity is transfer resistance r. r is the sum of two components: r_a the atmospheric transfer resistance and r_s the surface transfer resistance. r_s is much greater than r_a for relatively inert gases (e.g. CH_4, H_2O, CO) and most particles. That is, their uptake is controlled by surface characteristics rather than atmospheric transport. On the other hand, dry deposition of reactive gases (e.g. SO_2, NH_3, HNO_3) is not only limited by the surface but also by atmospheric transport (r_a is at least of the same order of magnitude as r_s)

Dry Deposition Velocity Values

Dry deposition velocities can be determined by any method that simultaneously measures air concentration and deposition flux. Most determinations of particle dry-deposition velocity have been made in wind tunnels. The dependence on particle size is illustrated by results for water surfaces shown in Figure 6. Note that V_d is a minimum for particles between 0.1 and 1 μm diameter. Smaller particles than these are deposited rapidly by brownian diffusion and larger ones by impaction/interception. Impaction and interception becomes more effective as surface roughness and wind speed increase. The particle-size dependence of deposition to other surface types (e.g. corn fields, snow) is similar to that for a water surface.

The largest body of deposition data in existence is for sulphate particles and sulphur dioxide gas. Recently an international panel of scientists reached the following conclusion about particulate sulphur (Dubrovnik 1978):

"Most sulphate mass lies in the particle-size range 0.1 to 1 μm diameter for which the deposition velocity is not

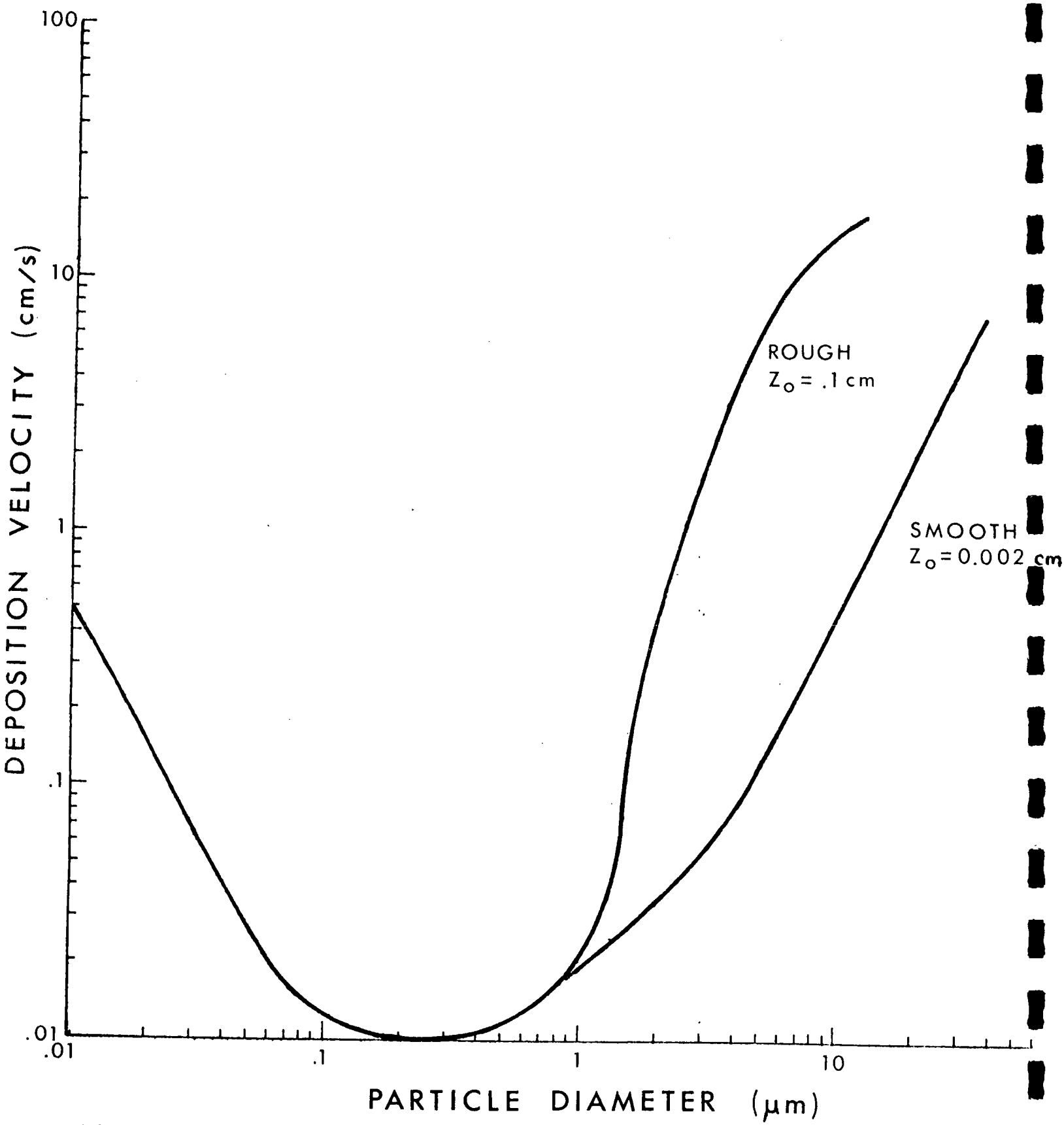


Fig. 6 - The dependence of deposition velocity of particles to a water surface on particle size and surface roughness z_o (adapted from Slinn et al, 1978).

expected to exceed 0.1 cm s^{-1}".

Typical SO_2 deposition velocities to vegetation and soil are listed in Tables 3 and 4. SO_2 deposition velocity to snow is typically 0.05 - 0.4 cm s^{-1}(Barrie and Walmsley 1978), to water 0.2 - 1.5 cm s^{-1} and to cities approximately 0.7 cm s^{-1}.

Little is known about the deposition velocity of gases other than SO_2. Estimates of the uptake of several gases by oceans have been made (Liss and Slater, 1974). The transfer resistance of ocean-water inert gases such as N_2O, CO, CH_4 is controlled by liquid phase transport and deposition velocities are correspondingly low; 0.006 cm s^{-1}. Ocean reactive gases such as SO_2 have much higher deposition velocities typically 0.4 cm s^{-1}. Their transfer is controlled by atmospheric processes as well as by surface water diffusion.

Measurement Of Dry Removal

Dry deposition is measured by several methods. They include:

1. eddy correlation flux technique. Flux is given by $\overline{w'\chi'}$ where w is the vertical wind speed, χ the air concentration. The superscript $'$ denotes instantaneous deviation from an average value over a time T (usually ½ hour) and $\overline{\ }$ denotes an average of values obtained in time T. This method requires pollutant and wind speed sensors with response times less than 1 second.
2. flux gradient technique. Flux is given by the product of an eddy diffusivity and a vertical concentration gradient. Vertical profiles of concentration, horizontal wind speed, and potential temperature are required.
3. collection by natural or artificial collectors followed by chemical analysis.

The first two methods are restricted to situations where the terrain is flat and homogeneous and where the pollutant con-

Table 3: SO_2 Deposition velocities over vegetation

Vegetation Height	Example	m Height	cm s^{-1} range of v_d	cm s^{-1} typical v_d*
short	grass	0.1	0.1 to 0.8	0.5
medium	crops	1.0	0.2 to 1.5	0.7
tall	forest	10.0	0.2 to 2.0	uncertain

* These values were obtained in a humid climate; much smaller values are likely in arid climates.

Table 4: SO_2 Deposition velocities over soil

	pH	State	cm s^{-1} range of v_d	cm s^{-1} typical v_d
Calcareous	≥ 7	dry	0.3 to 1.0	0.8
Calcareous	≥ 7	wet	0.3 to 1.0	8.0
Acid	-4	dry	0.1 to 0.5	0.4
Acid	-4	wet	0.1 to 0.8	0.6

N.B. As yet no information is available to access v_d on desert sand or lateritic soils.

centration does not vary during the averaging period. These conditions virtually exclude these techniques from being used to measure dry removal rates from a plume within 20 km of the source.

Artificial collectors have been in use for some time now, particularly in cities where they are called dust-fall collectors. They suffer the great disadvantage that deposition to them is not always representative of that to their surroundings. Before an artificial collector is used extensive calibration tests are required. Such tests are presently underway on two collectors in the Air Quality Research Branch of the Atmospheric Environment Service.

4. SUMMARY

Wet and dry removal processes are highly complex phenomena that are generally represented in transport-dispersion models by rather simple mathematical functions. The washout coefficient method is used for wet deposition. The dry deposition velocity approach is used to parameterize dry removal. Due to a lack of observational data and our inability to measure all parameters that influence removal rates, this approach is crude, but necessarily so. However, it does yield satisfactory estimates of wet and dry removal rates accurate to within at least a factor of three. The precision of an estimate is greatly improved by observational data.

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DISCUSSION/COMMENTS

H.P. SANDERSON: What method would you use to calibrate some of these devices with which you're collecting? How would you calibrate a wet collector or a dry collector? What's the difference really? I don't know whether that's been brought out or not.

L.A. BARRIE: Well, one of the biggest problems with calibrating wet collectors or precipitation collectors is it's representativeness. If you put out a network in a dense grid around your collector, and an event passes by, do you arrive at reproducible deposition with all of these, and there have been several large scale tests done in this manner, by deploying large numbers of precipitation collectors. The other way of calibrating, or problem with precipitation collection, is that the amount of precipitation collected, or falling on the ground, must be measured accurately, and usually we don't use our wet deposition collectors to measure that. We use a standard precipitation rain gauge. The rain that falls into the collector only supplies the precipitation chemistry, so in a deposition measurement where you multiply concentration times the precipitation amount, you use the precipitation amount from a standard gauge. Dry deposition collectors would be calibrated by generating artificial aerosols of known size, and measuring their uptake by natural surfaces, and at the same time as the collector is collecting.

H.P. SANDERSON: You mentioned Stoke's diameter. This size on the slides refers to a particle with unit density, does it not? A particle of lead, let's say, has a density much greater than one, and it would be a very much smaller particle in reality than on those slides.

L.A. BARRIE: Processes of intertial impaction and interception that I mentioned on these slides are dependent upon the particle's density.

H.P. SANDERSON: Not on the size?

L.A. BARRIE: Well, for a given particle size, interception and impaction would depend on density as well.

B.F.R. FINDLAY: When you're measuring snowfall, would you prefer to use snow on the ground measurements to collect your precipitation chemistry, or would you prefer to use a collector, such as you would use with rainfall? Is there any difference from an operational standpoint in your preference? I believe for example, that the collector that is used for rainfall is quite inaccurate, when it comes to collecting snowfall. Now I'm not sure whether this is inaccuracy in amount, I can believe that quite easily, but whether it is also just not adequate in collecting sufficient sample for analysis. In that case would you be obliged to use snow on the ground and sample it as one would do as say snow survey?

L.A. BARRIE: Well, that certainly is an approach which many people have used, myself included. Snow-pack sampling will give you total deposition, wet plus dry, whereas if you want only wet deposition, then you have to use some sort of wet collector, or snow collector. The way we measure wet deposition of snow is the amount of snow that has fallen is measured with a Nipher snow gauge, or a snow gauge with a Nipher shield, in the standard way. You'd then multiply precipitation amount determined by that gauge times the concentration of the

pollutant in snow amount to get the deposition.

R. LAWFORD: How does the wet deposition of hydrocarbons compare to the wet deposition of the compounds that you've been talking about? The comment is with regards to the accuracy of wet deposition measurements. You mentioned that the accuracy improved for a longer term averaging, and I guess my question is regarding your definition of accuracy. I assume that you mean you get a more reliable average value if you have a longer term sampling period. I guess my concern would be that for specific pollution events as far as, say, the fish in the lakes are concerned, that they would be interested in the acidic rain that fell in a particular synoptic situation, because that might be the one event during the month that really added to the acidification of the lake, and perhaps what we need are accurate event sampling periods and data for that type of analysis.

L.A. BARRIE: Well, I'm not saying because it's inaccurate we don't do it. As you saw in the APN network, we do sample precipitation on an event basis. It's just that you have to watch any predictions that you make, or temper it, due to the accuracy of it, and if you want very accurate measurements, you have to deploy hundreds of collectors for a single convective plot. I can't answer the first question in one sentence because it depends very much on the solubility of the organic. Some pesticides are very soluble, and their washout would be comparable to that of SO_2. DDT, for instance is fairly soluble.

R. LAWFORD: Yes, for some, not all.

H. FRASER: Len, where is the lab analysis done? Is it done here, or is it done elsewhere?

L.A. BARRIE: The precipitation analysis is done at CCIW, Burlington. The analysis of air samples that are collected (particulates are collected on filters and SO_2 is collected on impregnated filters) are done here in the chemistry laboratory in ARQA.

W.J. EVANS: Do you consider nitrates and chlorides as well?

L.A. BARRIE: Yes, we measure the particulate concentration of nitrates.

W.J. EVANS: Well, with regard to the acid rain problem, how much of the acid rain problem is sulphates?

L.A. BARRIE: Well, if you take for instance, on a micro-equivalent basis, the presence of nitrate is presently slightly less than of sulphate. There are situations in which it exceeds sulphate, but I would say on the average, just slightly less than sulphate.

OXIDATION OF SULPHUR DIOXIDE AND PHOTOCHEMISTRY IN POLLUTED ATMOSPHERES

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Atmospheric Chemistry, Criteria and Standards Division

INTRODUCTION

In this century, there has been a significant rise in anthropogenic sulphur dioxide and sulphate emissions. The former has been linked with direct adverse effects on humans, animal and plant life, as well as material damage. But, it is the sulphates that have more recently received attention in connection with the acidification of lakes (resulting with significant fish fill) and also with reduction in visibility (due to scattering of solar radiation by atmospheric sulphate particulates).

Even though less than 3% of the total anthropogenic sulphur emissions are in the form of sulphates, the sulphur dioxide emissions are readily converted to sulphates by atmospheric oxidation processes. Either species of course can be transported over relatively long distances (500-1000 km) before significant dry or wet removal has occurred.

In view of the present and foreseeable problems associated with sulphate aerosols and the present demands for more coal utilization, it is necessary that we understand the factors involved in SO_2 oxidation for a wide variety of atmospheric conditions. Many models have been and are currently being developed to predict the regional and long-range transport, dispersion and deposition of sulphur compounds. Presently, oxidation rates of 1 - 10% per hour have been employed. However, it is generally recognized that the development of scientifically sound and lasting strategy for sulphate aerosol control still requires more research. We must better understand the nature of the various atmospheric reactants which oxidize SO_2, the chemical nature of the products formed in its reactions, the rates at which these reactions will occur in a given atmosphere, as well as the physical processes which transport the gases or aerosols

about the atmosphere and those which remove them from it. Finally, measurements of the overall oxidation rates for given atmospheric conditions and chemical composition of the plume are necessary to validate the models. The Atmospheric Chemistry, Criteria and Standards Division (ARQA) has addressed itself to this latter activity. First though, it would profitable to briefly review some of the proposed mechanisms for oxidation of sulphur dioxide to sulphate (see references 1-4 for more details).

MECHANISMS FOR OXIDATION OF SO_2

A. Homogeneous Gas Phas Reactions

(i) Direct photo-oxidation of SO_2

$SO_2 + h\nu(240\text{-}400\ nm) \rightarrow SO_2^*$ (electronically excited)

$$SO_2^* + O_2 \rightarrow SO_4 \xrightarrow{O_2} SO_3 + O_3$$

$$\rightarrow SO_3 + O$$

$$SO_2^* + SO_2 \rightarrow SO_3 + SO$$

then $SO_3 + H_2O \rightarrow H_2SO_4$

Chemical model calculations show the maximum rates for these reactions to be less than 0.04% per hour. The observed rates of SO_2 oxidation in air are much higher than this. So this cannot be an important mechanism in the troposphere.

(ii) Reaction of SO_2 with electronically excited oxygen molecules

$$SO_2 + O_2^* \rightarrow SO_4 \xrightarrow{O_2} SO_3 + O$$

$$\rightarrow SO_3 + O$$

Oxidation rates of about $10^{-7}\%\ h^{-1}$ are expected, hence the oxidation by singlet oxygen can be neglected.

(iii) Reaction of O atoms with SO_2

$$O + SO_2 \rightarrow SO_3 \xrightarrow{H_2O} H_2SO_4$$

The oxidation rate is estimated to be about 0.012% h^{-1}. Again, this is a relatively unimportant mechanism.

(iv) $O_3 + SO_2 \rightarrow SO_3 + O_2$

It can be shown that the oxidation rate is less than $1.4 \times 10^{-5}\%\ h^{-1}$, again an unimportant reaction. This may sound surprising to some who have seen a correlation of O_3 concentration with high sulphate concentration. The answer lies in the next few reactions which accompany high O_3 episodes.

(v) $HO_2 + SO_2 \rightarrow HO + SO_3$

In the clean atmosphere, the oxidation rate in this reaction may be of the order of $0.2\%\ h^{-1}$; however under polluted conditions, e.g. urban atmospheres, this rate may be as high as $2\%\ h^{-1}$. So this reaction can be a major source of SO_2 conversion in the atmosphere.

(vi) $CH_3O_2 + SO_2 \rightarrow CH_3O + SO_3$

The oxidation rate of SO_2 through this reaction may be as large as $2\%\ h^{-1}$ in the polluted urban atmosphere and about $0.01\%\ h^{-1}$ in the clean troposphere. Again this is an important reaction to consider.

(vii) $HO + SO_2 \rightarrow HOSO_2\ (\rightarrow H_2SO_4)$

In the clean troposphere, oxidation rates of about $0.4\%\ h^{-1}$ can be expected; in the dirty urban environment, this could increase to about $2.7\%\ h^{-1}$.

(viii) Other reactions of SO_2 with organic radicals are not considered to be important at the moment.

In summary of the homogeneous gas-phase photochemically induced oxidation of SO_2, maximum summer time rates of about $4\%\ h^{-1}$ in polluted urban air and $1\text{-}2\%\ h^{-1}$ in unpolluted air can be expected. In the winter and spring (autumn) months, oxidation rates are lowered by factors of about 3 to 5.

HETEROGENEOUS MECHANISMS

(i) Oxidation of SO_2 by dissolved oxygen and ozone in water droplets.

$SO_2(g) + H_2O\ (\text{liquid}) \rightarrow H_2SO_3\ (\ell)$

$H_2SO_3\ (\ell) \xrightarrow[O_3]{O_2} H_2SO_4$

A high solubility for SO_2 may be sustained by dissolved atmospheric ammonia which neutralizes the sulphuric acid via $H_2SO_4 \xrightarrow{NH_3} NH_4HSO_4 \xrightarrow{NH_3} (NH_4)_2SO_4$

Here, the rate limiting factor is the availability of atmospheric ammonia.

Presently, it is thought that this aqueous phase oxidation of SO_2 is a viable and important atmospheric process but it seems that the presence of metal ions or ozone as catalysts is a prerequisite for such reactions. However, no representative oxidation rates can be assigned to this process for it depends very much on individual plume characteristics. Reported rates range from 0-20% h^{-1}.

(ii) Catalyzed oxidation on dry particulates.

This mechanism is similar to (i) except that the reactions occur at the gas-solid interface. It appears from the available data that reactions between SO_2 and solid particles in the atmosphere most likely will not lead to appreciable SO_2 oxidation, but mainly to chemisorption or adsorption of SO_2 on the particle surface. Again, no representative rate can be assigned but reported oxidation rates range from 0 to 6% h^{-1}.

AES FIELD STUDIES ON OXIDATION OF SO_2 IN PLUMES

At AES we have undertaken studies to measure the overall oxidation rate of SO_2 to $SO_4^{=}$ (5,6). This we have done for the plumes of the INCO smelter at Sudbury, Ontario and the GCOS power plant near Fort McMurray, Alberta. An interesting difference between the two plumes is that the latter plant also emits significant quantities of NO_x and hydrocarbons.

The sulphur dioxide and particulate sulphate in the plumes was measured by means of filter packs which efficiently trapped these pollutants. Traverses of the plume were made by aircraft at different downwind distances and under different meteorological conditions. From the change in sulphur dioxide

and sulphate, an average oxidation rate was derived.

The results from the INCO plume study indicate that the oxidation rate of SO_2 to sulphate is relatively slow, about 1% h^{-1} on the average. This rate was independent of temperature (-5 to 6°C in September and 12-21°C in June), relative humidity (40-90%) and solar radiation. The INCO plume is relatively low in NO_x and contains insignificant quantities of hydrocarbons; hence, a homogeneous oxidation scheme could at most account for about 0.25% h^{-1}. Our results indicated that for this plume, heterogeneous oxidation of SO_2 in droplets or on particulates was the predominant mechanism. A possible reason that the overall oxidation rate was low (in comparison to other studies elsewhere) is that the INCO plume is high in sulphuric acid. This would make the aerosols very acidic and in turn this would inhibit the solubility of gaseous SO_2, resulting in a lower oxidation rate.

This INCO study is to be contrasted with the one on the GCOS plume. Here, oxidation rates of up to 0.5% were measured in February and in the early mornings of June, 1977. However, the mid-day results of June showed oxidation rates of about 1-3%. We explained these results by a homogeneous gas-phase mechanism. This plume is relatively rich in NO_x and hydrocarbon emissions and therefore photochemical reactions can occur, leading to the formation of reactive intermediates which readily oxidize the sulphur dioxide. As before, no temperature dependence (-13 to 23°C) and no relative humidity (40-95%) dependence was found.

In conclusion to our studies, it may be said that modelling calculations, which in the past have used oxidation rates as high as 10%, must take note of these lower rates.

PHOTOCHEMISTRY IN THE URBAN POLLUTED ATMOSPHERE

We have noted how the rate of SO_2 oxidation is markedly increased by the presence of common urban pollutants, e.g. NO_x and hydrocarbons. It is within the polluted urban environment that reactive intermediates are generated as a result of photochemical interaction between sunlight and primary pollutants.

The term 'photochemical smog' was coined in the mid 1950's to describe air pollution episodes in Los Angeles, California. Today, this phenomenon occurs to some extent in most large cities of the world. Within these sprawling urban centres, one finds a high density of automobile traffic, industries and possibly even fossil-fueled power plants. This results in high concentrations of nitrogen oxides (NO_x), carbon monoxide (CO) and hydrocarbons. When these emissions are coupled with bright sunshine and poor atmospheric ventilation, some degree of photochemical smog formation is inevitable.

The characteristics of photochemical smog are:

(i) high oxidant levels, where the term 'oxidant' refers to any chemical species with high oxidizing properties (e.g. ozone (O_3), which usually amounts to about 90% or more of the total measured oxidant, peroxyacetyl nitrate (PAN, $CH_3COO_2NO_2$), nitrogen dioxide (NO_2), other perioxides etc.). It is these oxidants which are the annoying species in the sense that they cause eye irritation, odour etc.

(ii) haze formation with resultant reduction in visibility.

(iii) plant damage (e.g. in Ontario, ozone damage to white bean, onions and tobacco, as well as PAN damage to tomatoes, have been reported).

(iv) health effects on urban dweller (e.g. eye irritation from lachrymators such as PAN or acrolein (CH_2CHCHO) and some aldehydes; respiratory problems due to inhalation of oxidants or resulting aerosols).

(v) material damage (e.g. attack on fabrics, fading of dyes, or cracking of rubber). It is a well known fact that rubber under stress develops cracks in proportion to the ozone concentration.

Let us proceed with a simplified outline of the chemistry of photochemical smog formation (for greater details, the reader is referred to references 7-10). Figure 1 shows a generalized variation with time of day in the levels of NO, NO_2, hydrocarbons, aldehydes and oxidants. It is readily evident that NO and hydro-

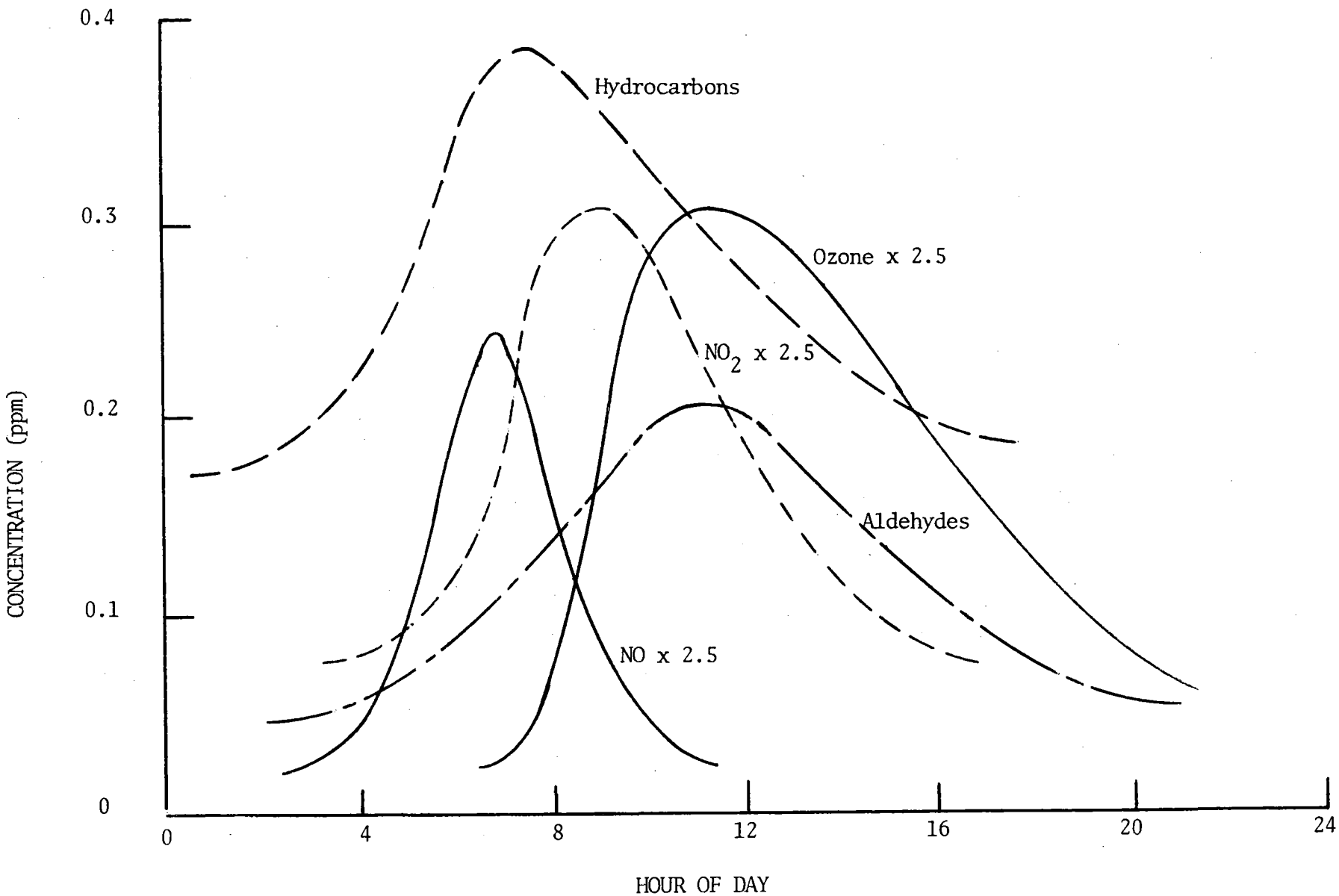

FIGURE 1: Generalized diurnal variation of photochemical smog species.

carbons peak early in the morning during the 'rush-hour' traffic and subsequently they decrease again. However, we note that there is a conversion from NO to NO_2 which peaks some time later. Finally, the ozone begins to increase noticeably only after the NO has decreased to small levels and the O_3 and aldehydes maximizes near the middle of the day. The explanation for the delay in the NO_2 and O_3 peaks is that they are not primary pollutants (not quite true for NO_2) but are produced photochemically in the atmosphere.

There are three chief reactions which control the O_3 concentration:

$$NO_2 + h\nu(290\text{-}430\ \text{nm}) \rightarrow NO + O \qquad (1)$$

$$O + O_2\ (+M) \rightarrow O_3\ (+M) \qquad (2)$$

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (3)$$

In equilibrium, one may show that

$$(O_3) \simeq 0.021\ \frac{[NO_2]}{[NO]}\ \text{ppm} \qquad (4)$$

(using data for a solar zenith angle of 40°, see reference 8).

Hence, one would expect very low O_3 concentrations (<10 ppb) for typical early morning NO_2/NO ratios of about 0.1-0.3. In theory then, one expects the O_3 concentration to follow the change in the NO_2/NO ratio; in practice this is nearly so. But the questions arise: what causes the rapid oxidation of NO to NO_2, what consumes the hydrocarbons, etc. It turns out that important chemical species in these photochemical processes are radicals, i.e. short-lived very reactive species like the hydroxyl radical (OH), peroxy radical (HO_2), organo-peroxy radicals like (RO_2) etc. In summary, one may write down the generalized equation

$$OH\ (\text{or } O_3,\ O) + RH\ (\text{alkenes, aromatics, alkanes etc.})$$
$$\rightarrow \alpha HO_2 + \beta RO_2\ (\text{or } RCOO_2) + \text{others} \qquad (5)$$

where OH radicals initially are formed from photolysis of aldehydes (emitted by auto exhausts) and nitrous acid (HONO).

The oxidation of NO to NO_2 is thought occur mainly via

$$HO_2 + NO \rightarrow NO_2 + OH \quad (6)$$

$$RO_2 + NO \rightarrow NO_2 + RO \quad (7)$$

$$RCOO_2 + NO \rightarrow NO_2 + RCO_2 \quad (8)$$

It is not to be overlooked that carbon monoxide can also participate via

$$OH + CO \rightarrow H + CO_2 \quad (9)$$

$$H + O_2\ (+M) \rightarrow HO_2\ (+M) \quad (10)$$

Reaction (10) is then followed by reaction (6) above.

The net result of these reaction mechanisms is the oxidation of NO into NO_2. This increases the NO_2/NO ratio, and as a result of the reactions (1) and (2) O_3 increases according to equation (4). Of course, this production of O_3 does not proceed indefinitely because of the limited amount of NO, the decreasing solar radiation after noon and the termination reactions. The latter include production of PAN via

$$CH_3COO_2 + NO_2 \rightarrow CH_3OO_2NO_2 \quad (11)$$

the formulation of alkyl nitrates via

$$RO + NO_2 \rightarrow RONO_2\ \text{(alkyl nitrate)} \quad (12)$$

and the formation of nitric acid, and to a smaller extent, nitrous acid via

$$OH + NO_2\ (+M) \rightarrow HONO_2\ (+M) \quad (13)$$

$$OH + NO\ (+M) \rightarrow HONO\ (+M) \quad (14)$$

$$HO_2 + NO_2 \rightarrow HONO + O_2 \quad (15)$$

$$NO_2 + NO + H_2O \rightarrow 2HONO \quad (16)$$

In the real urban atmosphere, PAN, nitric and nitrous acid can be as high as several ppb. It is the nitric and nitrous acids that can add to the acid burden of atmospheric sulphate aerosols mentioned earlier in the text.

As a final note, computer simulations have shown that water vapour content and temperature do not seem to have a

marked effect on maximum oxidant concentrations (see references 8 and 10). Also, at higher latitudes such as northern Canada, the potential for oxidant formation during summer months is almost as great as in the southern regions by virtue of the longer diurnal solar insolation.

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THE USE OF COMPUTERIZED GAUSSIAN DISPERSION MODELS IN AIR QUALITY APPLICATIONS

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ABSTRACT

Several prepackaged computer models which may be applied to air quality assessment are listed. The incorporation of Gaussian dispersion formulae in a sequence of increasingly more sophisticated computer models (ATDL - CDM - CRSTER - RAM) is outlined. The necessary computer resources and input data to apply these models and typical output from them are described.

INTRODUCTION

Table 1 catalogues some readily available Gaussian dispersion models. The first three in the list are essentially little more than dispersion formulae in the form of computer algorithms used for calculating concentrations due to point sources. The next five models (ATDL to RAM) will be described in more detail later. The final three models are designed for special purposes.

LIMITATIONS OF GAUSSIAN MODELS

The Gaussian plume equation is representative of steady-state conditions and a homogeneous atmosphere. Its use is less valid when emissions, wind speeds, directions, local turbulence and atmospheric stability are changing rapidly with time or distance. This steady-state condition translates into the following source and meteorological factors which must be considered (U.S. EPA, 1977):

Table 1. Catalogue of some Gaussian Dispersion Computer Models

MODEL	YEAR	DESCRIPTION
PTMAX	1973	Maximum short-term concentration from a point source as a function of stability and wind speed.
PTDIS	1973	Short-term concentrations downwind from a point source at specified distances.
PTMTP	1973	Short-term concentrations from multiple point sources at multiple receptors.
ATDL*	1972	Long-term concentrations from multiple point and area sources, using wind rose data.
CDM	1973	Long-term concentrations from multiple point and area sources, using STAR data.
CDMQC	1977	CDM plus peripheral routines.
CRSTER	1977	Concentrations for averaging times of 1 hour, 24 hours and 1 year from a single source.
RAM#	1978	Short-term concentrations for urban areas with gentle terrain; multiple point and area sources.
APRAC	1972	Short-term urban diffusion model; automotive contribution to Carbon Monoxide.
HIWAY	1975	Hourly pollutant concentration in the vicinity of a roadway.
VALLEY	1977	Maximum 24-hour concentration from isolated sources in rural, complex terrain.

*With the exception of the Atmospheric Turbulence and Diffusion Laboratory (ATDL) model, all models were developed by or for the U.S. Environmental Protection Agency and are available to the public through the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161 as part of the "UNAMAP" package.

#RAMF, a modified version of RAM,calculates frequency distributions of concentrations for a full year's data. Other versions of RAM are available for application to rural areas.

- continuous uniform emission rate
- homogeneous horizontal wind field
- constant wind speed and direction which are representative of the period considered (e.g., one hour)
- no directional wind shear in the vertical
- constant eddy diffusivities
- no plume history (i.e., no cumulative effects from previous periods)
- no material depleted and no atmospheric transformation.

These are rather severe limitations which are unlikely to be met in real situations. Nevertheless, they should be borne in mind whenever models based on Gaussian dispersion formulae are applied; results from such models may be invalid in cases of flagrant violation of the above limitations.

It should be noted that most Gaussian models employ dispersion parameters (in place of eddy diffusivities) which are functions of downwind distance and atmospheric stability. Some attempt to simulate depletion and transformation as functions of downwind distance.

GAUSSIAN FORMULAE

Following Novak and Turner (1976) these expressions are used in the Gaussian formulae:

$$g_1 = \exp(-0.5y^2/\sigma_y^2) \tag{1}$$

$$g_2 = \exp(-0.5(z-H)^2/\sigma_z^2) + \exp(-0.5(z+H)^2/\sigma_z^2) \tag{2}$$

$$g_3 = \sum_{N=-\infty}^{\infty} \{\exp(-0.5(z-H+2NL)^2/\sigma_z^2) + \exp(-0.5(z+H+2NL)^2/\sigma_z^2)\} \tag{3}$$

where

H = effective height of emission (metres),
L = mixing height (metres),
y = crosswind distance (metres),
z = receptor height above ground (metres),
σ_y = standard deviation of plume concentration distribution in the horizontal, or horizontal dispersion parameter (metres),
σ_z = vertical dispersion parameter (metres).

The infinite series in Equation (3) converges rapidly so that summation over the range N=-4 to +4 is usually sufficient.

POINT SOURCES

Defining x and y as the upwind and crosswind distances, respectively, of a point source from a receptor:

$$x = (S_p - S_r)\cos\theta + (R_p - R_r)\sin\theta \qquad (4)$$

$$y = (S_p - S_r)\sin\theta - (R_p - R_r)\cos\theta \qquad (5)$$

where (R_p, S_p) are coordinates of the point source, (R_r, S_r) are coordinates of the receptor and θ is the wind direction (i.e., direction from which the wind blows).

For <u>short-term concentrations</u> (e.g., one hour or less) from a point source the following Gaussian formulae are applicable:

(a) for stable conditions or unlimited mixing,

$$\chi_p = Qg_1g_2/(2\pi\sigma_y\sigma_z u) \qquad (6)$$

where χ_p = concentration ($g.m^{-3}$),
Q = emission rate ($g.s^{-1}$),
u = wind speed ($m.s^{-1}$),
σ_y and σ_z are functions of x and atmospheric stability;

(b) for unstable or neutral conditions with $\sigma_z \geq \sigma_{crit}$, $H<L$, $z<L$,

$$\chi_p = Qg_1/(\sigma_y Lu(2\pi)^{\frac{1}{2}}) \tag{7}$$

where σ_{crit} is a critical value taken to be, for example, 1.6L in the RAM model;

(c) for unstable or neutral conditions with $\sigma_z < \sigma_{crit}$, $H<L$, $z<L$,

$$\chi_p = Qg_1 g_3/(2\pi\sigma_y\sigma_z u) \tag{8}$$

(d) for $H>L$ or $z>L$,

$$\chi_p = 0. \tag{9}$$

Equation (7) is known as the limited mixing formula. Equation (8) takes into account multiple reflections within the mixed layer (see Figure 4). Equation (9) attempts to simulate lofting (emission above the mixed layer height) or the situation where a receptor is at a height above the mixed layer.

For <u>long-term concentrations</u> (e.g., seasonal or annual) from point sources a cross-wind average of Equation (6), (7) or (8) as appropriate, is used. All three equations may be written in the form

$$\chi_p(x,y,z) = \chi_p(x,0,z)\ g_1 \tag{10}$$

and hence,

$$\overline{\chi}_p(x,z) = \chi_p(x,0,z)\int_{-\infty}^{\infty} g_1\ dy \Big/ \int_{-\infty}^{\infty} dy \quad . \tag{11}$$

The integral in the numerator is simply $\sigma_y(2\pi)^{\frac{1}{2}}$. In the denominator the transformation $dy = x\ d\theta$ is employed; then it is assumed that the plume is "narrow", i.e., entirely contained

within a sector $\theta-\pi/M$ to $\theta+\pi/M$ (where M is an integer; usually M=16). Hence Equation (11) becomes

$$\overline{\chi}_p(x,\theta,z) = \chi_p(x,0,z)\ \sigma_y(2\pi)^{\frac{1}{2}}\ (M/2\pi x) \quad . \qquad (12)$$

The factor σ_y will cancel and the factors (2π) may be combined for convenience when Equation (12) is applied to (6), (7) or (8). Equation (12) is the basis for computations in the ATDL and CDM models to be described shortly.

AREA SOURCES

The contribution of the concentration χ_a, from a uniform area source directly upwind of a receptor is (Novak and Turner, 1976):

$$\chi_a = (q_a/u) \int_{x_2}^{x_1} f\ dx \qquad (13)$$

where χ_a is in $g.m^{-3}$, q_a is the area source emission rate in $g.s^{-1}.m^{-2}$, x_1 and x_2 are appropriate distances upwind of the receptor and f is given by one of the three equations below corresponding to the conditions applicable in Equations (6), (7) and (8), respectively:

$$f = g_2/(\sigma_z(2\pi)^{\frac{1}{2}}) \qquad (14)$$

$$f = 1/L \qquad (15)$$

$$f = g_3/(\sigma_z(2\pi)^{\frac{1}{2}}) \quad . \qquad (16)$$

LONG-TERM CONCENTRATION MODELS

Both the ATDL (Hanna, 1972) and CDM (Busse and Zimmerman, 1973) models (see Table 1) compute seasonal- or annual-averaged concentrations at ground level over uniform terrain. The dispersion formulae used in both models is based on

Equation (13) for area sources and Equation (12) for point sources with z=0, M=16 and with a frequency of occurrence, F, multiplier. In the case of the ATDL, F is simply the wind rose, i.e., a function of wind direction sector centred at θ_m , where m=1 to M; in the CDM, F is the STAR data set, i.e., a function of θ_m , atmospheric stability and wind speed. Thus for point sources:

$$\overline{\chi}_{ATDL} = \overline{\chi}_p(x,\theta_m,0)\ F(\theta_m) \tag{17}$$

$$\overline{\chi}_{CDM} = \sum_s\sum_u \overline{\chi}_p(x,\theta_m,0)\ F(\theta_m,s,u) \tag{18}$$

where s is atmospheric stability. Summation over all upwind point sources is also performed for each receptor in both models.

It should be noted that the ATDL assumes only unlimited mixing conditions, Equations (6) and (14), whereas CDM uses Equations (6), (7) or (9) for point sources and (14) or (15) for area sources, according to the following criteria:

(6) or (14)	$\sigma_z \leq 0.8L$, $H<L$
(7) or (15)	$\sigma_z > 0.8L$, $H<L$
(9)	$H>L$.

In the CDM removal processes are represented by an exponential decay multiplier: exp(cx/uT), where c=ln(0.5)=-0.6931 and T is the pollutant half-life (seconds). The multiplier thus has values of $1/2^n$ at distances x=nuT; for an input half-life of 10 hours (36 000 s) and a wind speed of 5 $m.s^{-1}$, pollutant concentrations would be reduced to half the undepleted values at a distance of 180 km.

For both the ATDL and the CDM, input data consist of emission grid and map grid parameters; location, height and emission rate of pollutant sources; receptor locations and meteorological frequency data, F, needed in Equations (17) or (18). Additional input data required by the CDM are representative afternoon maximum and nocturnal minimum mixing heights

and data needed for plume rise computations (stack diameter, stack exit velocity and stack gas temperature in addition to a representative atmospheric temperature).

Table 2 compares several characteristics of the ATDL and CDM models. Figure 1 provides a sample of CDM output from Walmsley and Bagg (1977) who added a contour mapping routine to the basic CDM.

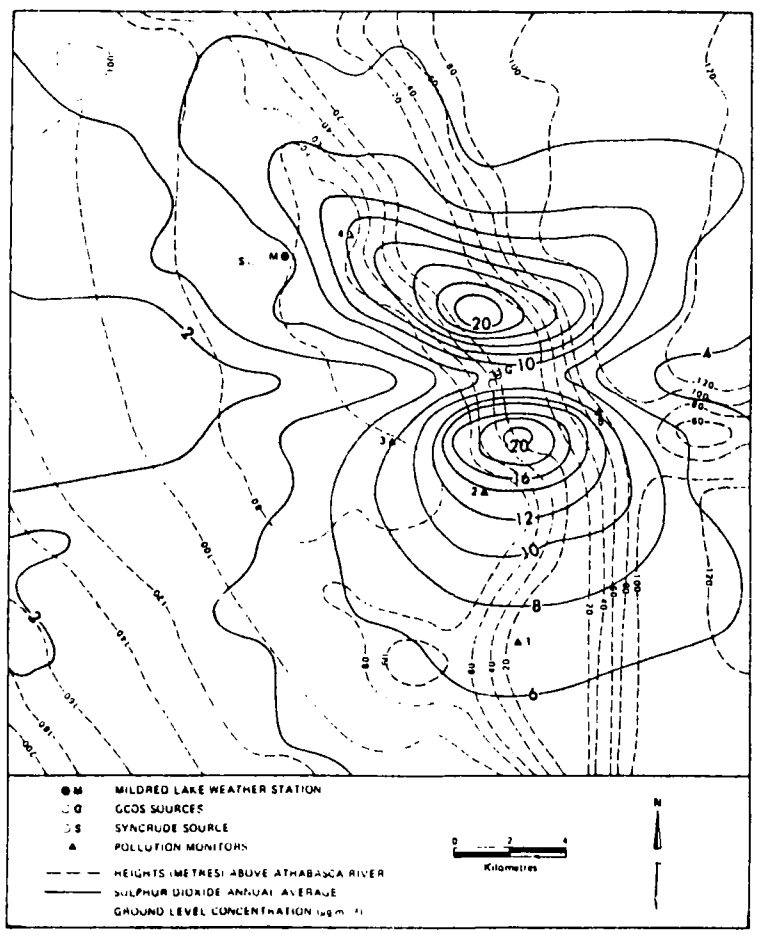

Figure 1. Sample of CDM Output (Walmsley and Bagg, 1977)

Other peripheral routines (source contribution table, internal calibration and statistical conversion of averaging times) were added in CDMQC (Brubaker et al., 1977). The Walmsley and Bagg (1977) study pointed out the need for obtaining STAR data representative of the vicinity of the emission sources; Walmsley and Bagg (1978) outlined a method of obtain-

Table 2. Comparison of ATDL and CDM

CHARACTERISTIC	ATDL	CDM
Area Sources:		
Maximum number	900	2500
Size	Δx	$n\Delta x$, n=1,2, ...
Point Sources:		
Maximum number	300 (30 in each of 10 height classes)	200
Pollutants:		
Maximum number	1	2
Receptors	at centres of grid squares	Unlimited number; any location
Meteorological input data	Wind rose (16 point). Wind speed. Stability class.	STAR Frequency data, Day/Night version (576 categories). Mixing Heights (Maximum & Nocturnal)
Adjustment of wind speed to stack top height	No adjustment.	Power law, stability dependent.
Plume rise	Not included; input is effective source height.	Choice of Briggs or Holland formula for each point source.
Dispersion Formulae	Cross-wind averaged Gaussian in each wind direction sector	Cross-wind averaged Gaussian in each wind direction sector; limited mixing for $\sigma_z > 0.8$ L.
Removal processes	None	Exponential decay.
Sector integration	Grid-square weights	Trapezoidal
Calibration	None possible	Calibration constants obtained from regression analysis using observed concentrations.

ing representative data by correlation of winds at a pollutant source site with winds observed at a nearby meteorological station.

THE CRSTER MODEL

The Single Source (CRSTER) Model is a steady-state, Gaussian plume dispersion model designed for point-source applications. It calculates pollutant concentrations for each hour of a year at 180 receptor sites on a radial grid. The hourly concentrations are averaged to obtain concentration estimates for time increments of specified length (e.g., 3-hour, 8-hour, 24-hour and annual). The model contains the concentration equations, the Pasquill-Gifford dispersion coefficients and the Pasquill stability classes as given by Turner (1970). Plume rise is calculated according to Briggs (1969). No depletion of the pollutant is considered. Technical details of the programming are presented with complete descriptions of data requirements and output in U.S. EPA (1977) which also includes papers on application, sensitivity and validation of the model. Figures 2 to 6, taken from the user's manual, serve to illustrate some of the concepts incorporated in CRSTER.

Although a single-source model, CRSTER can consider up to 19 stacks located at a common site. The model may be applied to problems such as stack design, monitor network design, fuel conversion studies, and design of supplementary control systems.

Figure 2 displays a flow diagram for processing of data by the single-source CRSTER model. The preprocessor program is executed independently and transforms surface and upper air meteorological data to the input format required by CRSTER. Other operations performed include calculation of hourly values of atmospheric stability from meteorological surface observations and interpolation of twice-daily mixing height data to hourly values (see Figure 3). The hourly surface observation data needed for input to the preprocessor consists of wind direction and speed, air temperature, sky cover and cloud ceil-

ing height. Output of the preprocessor consists of hourly values of wind speed, flow vector, randomized flow vector, stability class, mixing heights and ambient temperature.

Input data requirements for CRSTER itself includes program control parameters, source emissions (similar to the requirements of the CDM), receptor site data (see Figure 6) in addition to the preprocessed meteorological data.

Output generated by CRSTER consists of printouts of input data, concentration tables, source contributions and additional mass storage output (tape or disk) of calculated concentrations. A small sample of this output is shown in Table 3. Other printout includes annual mean concentration at each receptor, highest 24-hour concentration at each receptor, second-highest 24-hour concentrations, highest and second-highest concentrations for other periods and maximum concentrations for various periods arranged in order as in the example in Table 3.

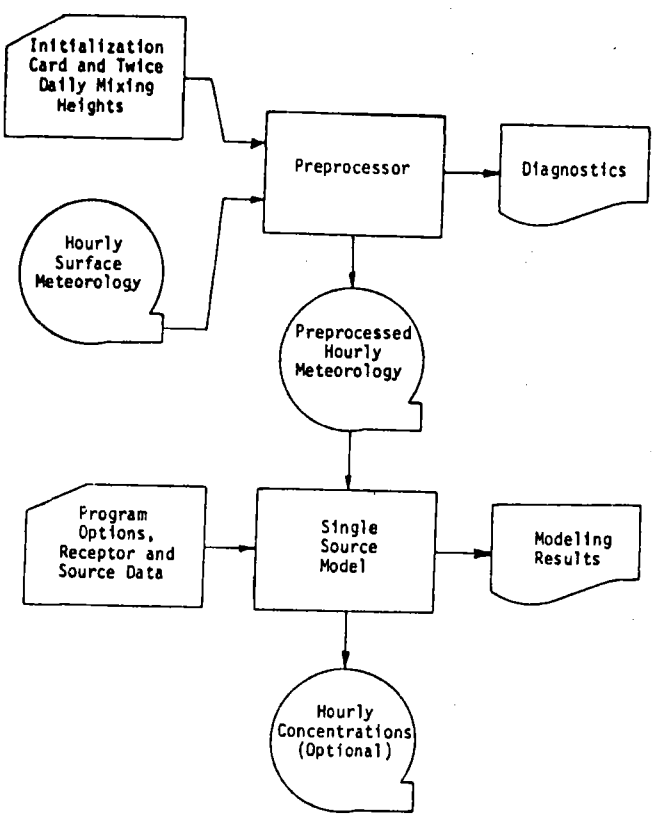

Figure 2. Flow Diagram for Meteorological Preprocessor and CRSTER Model. (U.S. EPA, 1977)

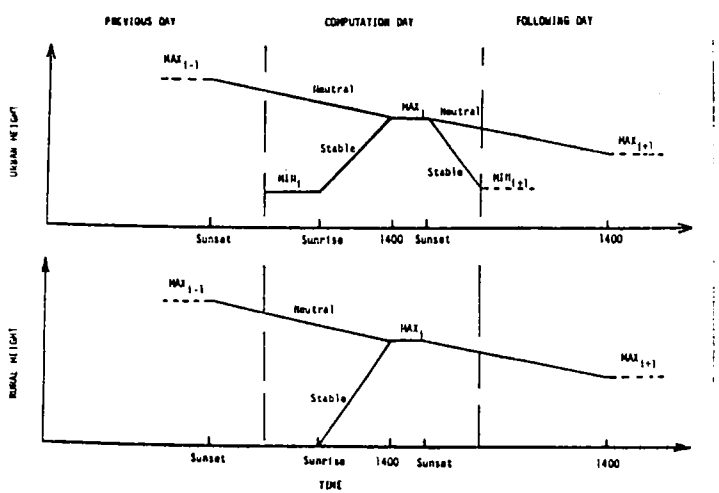

Figure 3. Determination of Hourly Mixing Heights by CRSTER Meteorological Preprocessor (U.S. EPA, 1977)

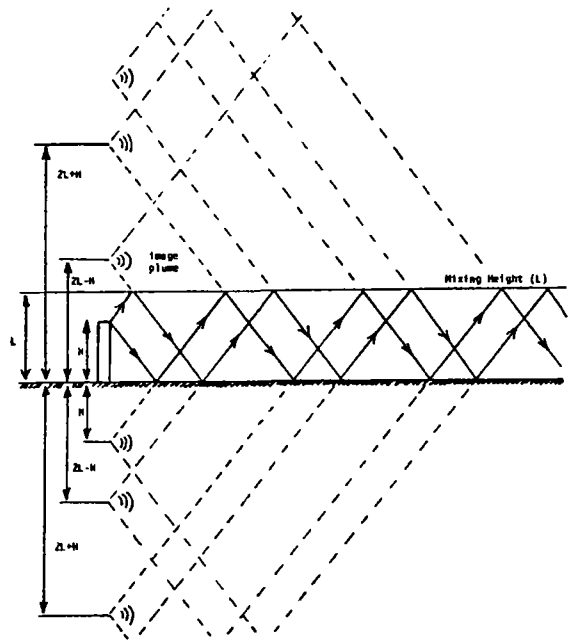

Figure 4. Method of Multiple Plume Images Used to Simulate Plume Reflections in the CRSTER Model (U.S. EPA,1977)

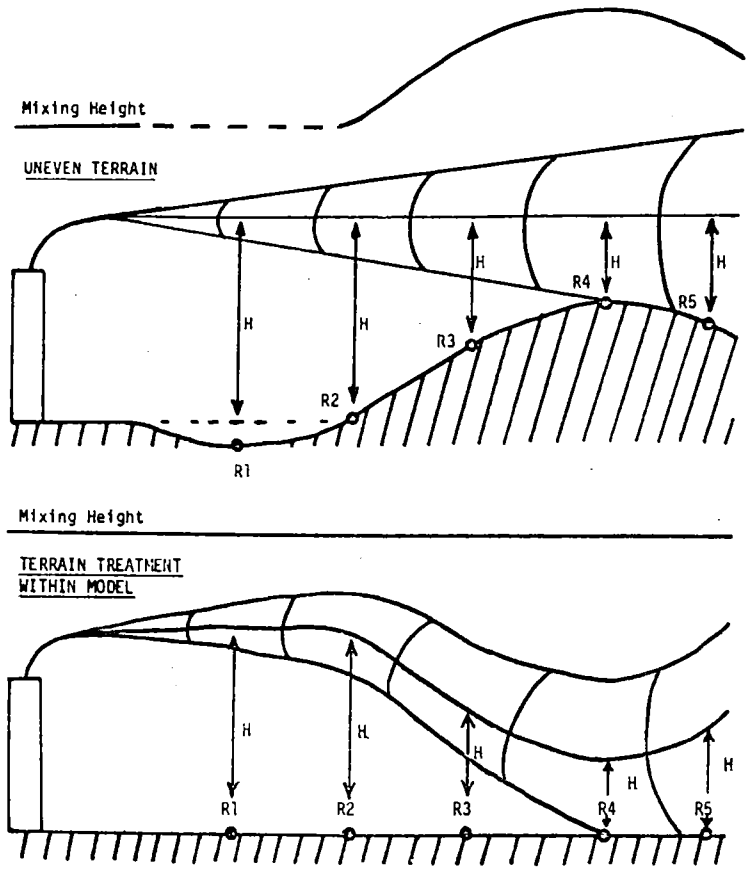

Figure 5. Method of Terrain Adjustment in the CRSTER Model (U.S. EPA, 1977)

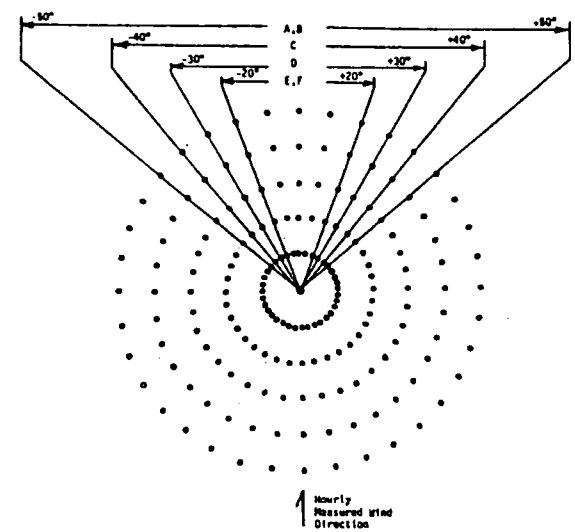

Figure 6. Example of Receptor Network Used in the CRSTER Model for a South Wind and for Each Stability Class (U.S. EPA, 1977).

Table 3. A Small Sample of the Output Generated by the CRSTER Model (U.S. EPA, 1977)

PLANT NAME: EXAMPLE RUN

POLLUTANT: SO2 EMISSION UNITS: GM/SEC AIR QUALITY UNITS: GM/M**3

MAXIMUM DAILY CONCENTRATIONS

DAY	24-HOUR CONCENTRATION	DIRECTION	DISTANCE
129	2.4790-04	4	3.80
140	2.3068-04	7	6.20
145	2.0398-04	4	1.50
141	1.9818-04	20	2.00
126	1.8967-04	4	3.80
127	1.8588-04	3	3.80
130	1.8459-04	7	6.20
128	1.7147-04	4	3.80
142	1.6583-04	15	1.50
131	1.6547-04	10	3.80
134	1.5318-04	7	6.20
146	1.4285-04	26	2.00
125	1.3145-04	2	3.80
144	1.2320-04	4	3.80
148	1.2135-04	15	3.80
143	9.6394-05	6	2.00
147	9.1085-05	3	3.80
132	8.6754-05	30	6.20
133	8.5918-05	7	6.20
149	5.6766-05	21	6.20

THE RAM MODELS

RAM is the designation for a system of Gaussian-plume, multiple-source air quality algorithms which can be used for estimating air quality concentrations of relatively non-reactive pollutants for averaging times from one hour to one day from point and area sources. The algorithms are applicable for locations with level or gently rolling terrain where a single wind vector for each hour is a good approximation to the flow over the source area considered. Calculations are performed for each hour. Options are available to allow use of three different types of receptor locations: (a) those with specified coordinates, (b) those with coordinates determined by the model to be downwind of significant point and area sources and (c) those with coordinates determined by the model to give good area coverage of a specific portion of the region.

The eight main programs in the RAM system consist of the four versions of RAM: RAM, RAMR, RAMF and RAMFR; three preprocessor programs: RAMQ, RAMMET and RAMBLK; and one postrun processor: CUMF. The relationships are shown in Figure 7.

Two of the versions (RAM and RAMF) have dispersion parameters representative of urban areas (roughness lengths about 1 m). The other two versions (RAMR and RAMFR) are for rural conditions (roughness lengths about 0.03 m).

RAM and RAMR are intended for application to one or several days but not for long periods of record. These versions have a full range of options available. The RAMF and RAMFR versions calculate frequency distributions of concentrations for a full year's data; therefore to reduce computing time most of the options of RAM are not available. The postprocessor, CUMF, is used with disk output for runs of RAMF or RAMFR to determine cumulative frequency distributions of 24-hour concentrations for each receptor location.

Regarding the RAM preprocessors, RAMBLK produces data which help determine distance to maximum concentration, RAMQ processes emission data and RAMMET is a meteorological preprocessor with functions similar to the one used by CRSTER.

RAM model programs require up to 41 000 storage locations for programs and data, depending on which of the eight main programs is being run. Execution time is highly variable (e.g., 5 seconds to 30 minutes in the user's guide) depending on the program and options selected.

A sample of the output from RAM is provided in Table 4.

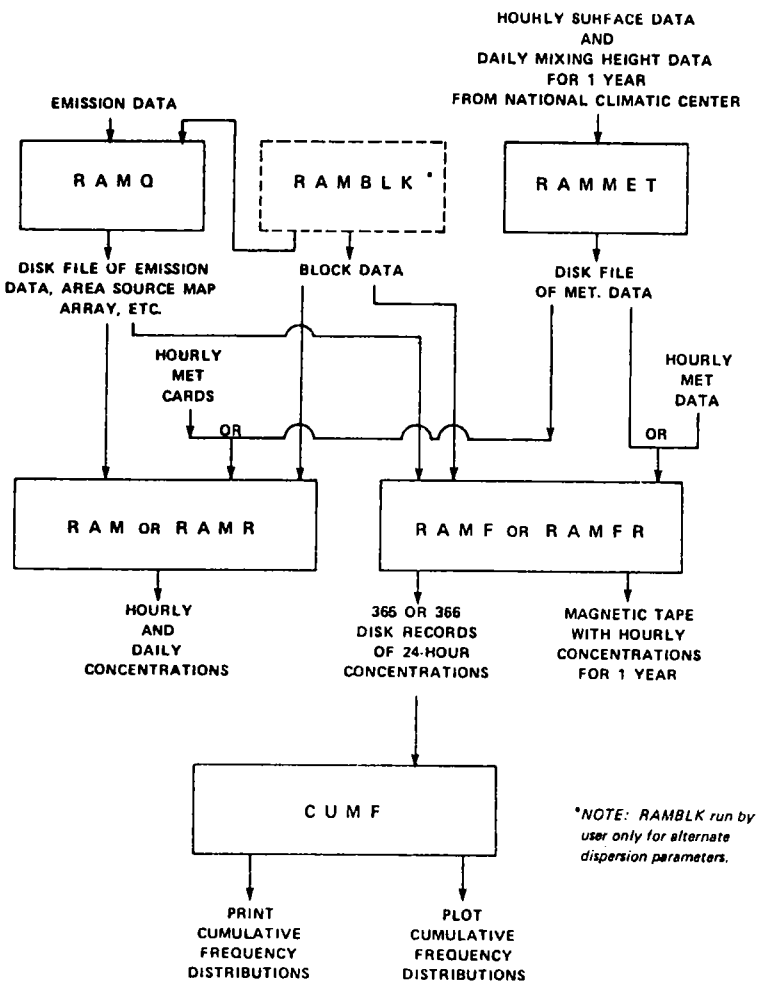

Figure 7. Flow Diagrams for the RAM Models (Turner and Novak,1978)

Table 4. A Sample of the Output from RAM (Turner and Novak, 1978)

RUN BY: (D KRENSHAW, AIR & HAZARDOUS MATER. DIV., REGION XV,EPA(1 JAN 78)
EMISSIONS: TEST CITY, 1973
SFC MET. DATA: TEST CITY 1973 ; UPPER AIR: TEST CITY 1973

SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 73/ 1 : HOUR 1

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (K)	STABILITY CLASS
1	32.00	2.17	429.11	259.82	6

AREA HTS: 11., 14., 19.; SEPARATION HTS: 12., 16.

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 I C	566.00	4405.00	.0000	.0000	.0000	.0000	.0000	41
2 I C	564.00	4401.50	.0000	.0000	.0000	.0000	.0000	40
3 F 7	564.43	4407.01	35.7987	35.7987	.0000	.0000	35.7987	11
4 F 7	564.16	4406.52	18.2026	18.2026	.0000	.0000	18.2026	15
5 F 5	579.45	4403.16	723.7571	723.7571	1.4215	1.4667	725.2238	1
6 F 5	579.40	4403.57	368.0487	368.0487	1.4465	1.4929	369.5415	5
7 F 8	577.38	4401.21	431.7821	432.2024	2.7281	2.7281	434.9305	3
8 F 8	577.30	4401.08	204.7343	205.1913	2.8280	2.8280	208.0193	7
9 F 9	576.67	4400.55	710.0658	712.6823	2.9602	2.9602	715.6425	2
10 F 9	576.59	4400.40	291.1613	293.7612	3.0427	3.0427	296.8038	6
11 F 11	582.94	4400.20	433.3493	433.3493	.0000	.0483	433.3975	4
12 F 11	582.89	4400.70	194.8263	194.8263	.0000	.0445	194.8708	8
13 A 4	578.42	4399.94	.0837	.0837	3.2543	3.4000	3.4837	24
14 A 3	576.43	4399.95	49.8623	51.6786	3.0888	3.0888	54.7674	9
15 A 5	575.43	4401.96	7.9795	7.9803	1.7745	1.8009	9.7811	21
16 A 9	578.43	4405.95	.0000	.7536	1.1665	1.1665	1.9200	25
17 A 2	574.43	4399.96	.0000	13.9389	1.6338	1.6338	15.4727	17
18 A 10	580.41	4405.92	.0000	.0000	.8464	.8464	.8464	29
19 A 8	574.43	4405.96	.0000	.5625	1.0529	1.0529	1.6154	26
20 A 7	570.87	4403.94	.0000	.0000	.4950	.5121	.5121	33
21 A 13	582.41	4403.92	.0000	.0000	.5493	.6120	.6120	31
22 A 12	580.41	4403.92	.0000	.0000	.5444	.6414	.6414	30
23 W 0	572.00	4400.87	.0000	26.2047	.1834	.3421	26.5468	13
24 W 0	574.00	4400.87	.0000	8.6048	1.2702	1.2702	9.8749	20
25 W 0	580.00	4400.87	.0000	.0000	.2272	.3489	.3489	37
26 W 0	571.00	4402.60	.0000	.0214	.3706	.4890	.5104	34
27 W 0	573.00	4402.60	.0000	19.4521	.2353	.3536	19.8057	14
28 W 0	575.00	4402.60	.0000	9.4123	.1610	.1610	9.5734	22
29 W 0	577.00	4402.60	.0000	29.5180	.3822	.3822	29.9002	12
30 W 0	572.00	4404.33	.0000	.0028	.5696	.5696	.5724	32
31 W 0	574.00	4404.33	.0000	7.2180	.2753	.2753	7.4933	23
32 W 0	576.00	4404.33	.0000	10.9692	.1248	.1248	11.0931	19
33 W 0	578.00	4404.33	.0000	45.5482	.4121	.4121	45.9603	10
34 W 0	571.00	4406.06	.0000	.8200	.3788	.3788	1.1988	27
35 W 0	573.00	4406.06	.0000	.0001	.4319	.4319	.4320	36
36 W 0	577.00	4406.06	.0000	12.9563	.0959	.0959	13.0522	18
37 W 0	572.00	4407.79	.0000	.0000	.1342	.1342	.1342	39
38 W 0	574.00	4407.79	.0000	.0000	.4364	.4364	.4364	35
39 W 0	576.00	4407.79	.0000	.9420	.0000	.0000	.9420	28
40 W 0	578.00	4407.79	.0000	15.2102	.4971	.4971	15.7073	16
41 W 0	580.00	4407.79	.0000	.0000	.2645	.2645	.2645	38

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DISCUSSION/COMMENTS

S. DAGGUPATY: I have doubts when you include the removal processes in this Gaussian plume hypothesis. Do you include the imaginary source term, that is the (z-h) term or not? Is it compatible?

J.L. WALMSLEY: I don't know.

J.D. REID: What do you feel AES should be doing in developing Gaussian models? Are there any plans, do you have any particular opinions?

J.L. WALMSLEY: I don't have any plans; I'm not sure that we should be spending a great deal of effort developing Gaussian models. I think that there are a number available. Perhaps we could look at refining the existing ones for Canadian situations, but I think it would be a duplication of effort really, to get heavily into Gaussian model development. I think we should concentrate our effort on other types of models that you're going to talk about perhaps.

IMPLEMENTATION OF USER MODELS

R.V. PORTELLI & J.W.S. YOUNG

PRESENTATION AND DISCUSSION

R.V. PORTELLI: The title of this presentation is "Implementation of User Models" - we haven't really discussed this type of activity very actively before, therefore I'll give some background. There have been over the last four or five years since I became involved with the Air Quality and Environmental Research Branch, a number of demands and requests upon ARQD to provide support/assistance in various environmental impact assessments, air quality assessments in particular, and there have been to date quite a few which we have not been able to respond to with something which could be considered to be readily available. I believe we have a national centre for atmospheric research here, which has developed a very strong capability and expertise in air quality modelling, and in terms of who should be responsible for providing some guidance or some developmental or adaptive work on modelling in support of regions, I open this up to this discussion. We wish to determine from regional view points what might be required, not only by AES regions, but also by provincial agencies, other federal agencies, and consultants So if we throw on the first overhead I would like this to be somewhat of an open forum and I will maybe direct questions to individuals who I know have some feelings about these matters. The first one is "Is there a need for ARQD to make air quality models available for use in the regions." If there is no such need then we should not be pursuing this course of action. My feeling is that from the types of requests in the past, there are. Would anyone like to offer his opinions, or concerns, and give us an indication of what the needs might be.

H. FRASER: Well, I'm not here to claim that we have a day by day high use of modelling, and I think therein our models, and therein lies part of our problem. We have what you might call the occasional need for a model, and it's the occasional need of perhaps one of a variety of models, and that is part of our problem. I don't think that we will be able to attain in the region the sort of expertise to develop and maintain the range of models, for instance, that we've heard about today. I think perhaps our main use is in the point source type of models, of which we now have the ones that have been supplied from here, but we also are interested in area and line source models, and in the Star program, and so forth, but as I say, we don't work on this for a major portion of our time; it's only occasional use. Our problem is how could we possibly maintain the sort of library and expertise in using these things when we don't use them a lot.

R.V. PORTELLI: Hugh, if you don't mind I'd like us to stop there for a second. I think we will try to identify the level of interaction. I am concerned as to identifying a base need, if it exists, and if it does, there has to be a point at which we decide where not to go any further, because for example, I would not recommend trying to have the RAM model incorporated in any region at this point in time. It's just very complex to even mount and run never mind being extremely knowledgeable about it. That we'll deal with a little later. I'd just like an indication of whether we're in the position of providing support to a need. Is there anyone else who would like to address this? I think from the Ontario view point Rick Lawford provided me with some comments, and he indicated, since he wouldn't be here, that he'd like me to read some of them. His interests would be that we provide a listing of all models and specify the applicability of such models, the degrees of uncertainty in the models, things

of that nature. Areas where he would like specific action, (the Ontario region would like specific action) he states "ARQD should take action to satisfy the following immediate regional requirements: Dispersion models for point and area sources for use in regional computers or a large desk-top calculator as we had demonstrated yesterday in the problem solving session. Climatological models to give long-term concentration estimates. Regional transport models for use in a regional computer or central computer system with real-time and historical data. A handbook showing the effects of topography features, sea breeze circulation, etc. In other words, some guidline or instructive material on the models that are available, some specific models for defined needs right now, and then the documentation on these. Do we have any expressed needs from the Atlantic region?

E. BRANDON: Yes, we have several of the smaller models, and we along with the EPS, spent a couple of days running some of these models, using some data from Newfoundland at the request of the Newfoundland Government just recently. We have also run the CDM model, and I think it would be useful to have some of the larger models, such as the ATDL model, reside on the CYBER for regional use, as does the CDM model. I have no doubt in my mind that there is quite a large requirement for models in the regions. We work very closely with EPS, and together we find that we do need these models quite frequently. We would like to have some smaller type models that could be run on a small mini-computer or a desk-top calculator, which incorporate terrain effects and channelling and that sort of thing. There doesn't seem to be any on the market at the present time.

R.V. PORTELLI: If there is no one else who would like to speak about this, I would like to interject by saying that it is the view of some, that where research is done in a particular area, so also should the applications be done. We had comments the other day that to the level of effort that has been extended so far on this area, it's been quite small, but it should not grow to the detriment of research, and I think this is an important point to bear in mind. With respect to other concerns and requirements, we've been criticized by services like the Environmental Protection Service, for not coming across and developing or adapting and implementing models which could be utilized by some of their people, and so what they have done is they have gone ahead and they've developed some of their own, which have been reviewed here from time to time and have been found to be inadequate, because not enough of the meteorological considerations are incorporated. So if we are the meteorological base, air quality base, my view is that we had better attempt to provide some guidelines or guidance in this respect. If we'd go to the next overhead, this deals with provincial agencies and industry and other federal agencies. I'm just wondering whether there are pressing requests from the private sector or the provincial sector with regard to our regional people being put on the spot for this type of information. The central region informed me that the simple point source models which were provided to them were being requested by various groups, and at that time no policy decision or statement had been made with respect to the relinquishing of these models. It was my concern that we should not relinquish such until we have identified not solely on an individual basis, how we should disseminate this information, how we should review it, so that we do not have groups seconding models from AES and saying we used the AES model, and therefore at a public hearing we should be in the right. Is there anyone who would like to voice an opinion with respect to provincial agency concerns or industrial concerns?

S. NIKLEVA: I think that probably most of the provinces have their own models now, and I think the other points you make, about that we shouldn't be involved in providing models is a very real one, because this is one of the things that is always being brought up by consultants at hearings; they say well we've gone to AES and they gave us this information, it was all that was available, so we've done the best job. So I don't think that we should get involved in that. Where I find our involvement, and this goes with EPS and with the province, isn't so much... I think we should have a model to use for our own purpose; I'll make that statement first, but I think what we're always asked even from EPS who have access to similar types of models, is they come to us and ask well, does this model apply here? In our case usually it doesn't apply because of mountains or something like that. So this is always the question we're asked; because these models are available to all consultants, I'm sure, that are involved in it, it's not really to produce what the models produce, but to comment on the deficiencies and how they can be corrected or improved. So I see a real need in that area, rather than just straight model development.

R.V. PORTELLI: With respect to that point, it's been raised to me, how does one make an evaluation of such models? For example, say a consultant has done an assessment in your area and it's been brought to you to attempt to identify whether the estimates are reasonable or not. Do you feel that this is done sort of like a behind the desk operation where you say, well these equations seem to be the right ones used, and the assumptions appear to be correct? Would you feel it necessary to have a model in-house such that you would be able to do, in a very short order of time, a preliminary run to see if there's an order of magnitude comparison at least?

S. NIKLEVA: Well, I think the use of whatever the model the consultants are using, that actual part of it I don't think is ever a problem. You might comment on whether it's applicable, but there is a problem there on how the data source is used, and usually this requires quite a lot of digging, going back to the consultant because it's not in the EIS, whatever it is, so he has to go back there and find out just how he's got the data, how he's classified it, and from that you find out deficiencies in the use of the data. That's one aspect, when we're talking about who does AES's, I think we can do in the region. Now the other part of it on whether that is applicable because of terrain affects or something like that, well this is where we often feel that we can send these things along to you, and you're the experts in it, and you should be able to provide this information, and if you can't well then the people in the region have to develop quite a high level of expertise in order to do it.

R.V. PORTELLI: Maybe, since it appears that we do have some people from the private sector, just a comment from maybe Boris (Weisman) or John (Bober) with respect to a consultant's view on this.

B. WEISMAN: One point that was just discussed, I find kind of strange, the fact that you're looking at AES providing these models to your own agencies to evaluate environmental impact statements, and you don't want to see the consultants using the same models, I would think if you think that that model is appropriate...

R.V. PORTELLI: No, not at all. I disagree on what you said. Not that they shouldn't be made available...

B. WEISMAN: That they can be made available but they shouldn't be brought up in a public hearing as being recommended by AES. I think that's wrong; your job is to provide models, maybe not provide them in the form of computer print-out, but I think your job is to evaluate potential models that should be sort of a yardstick for what kind of modelling should be done, and what answers consultants get should compare to. They shouldn't be used as a private domain of the environmental agencies, and keep the consultants out of there.

R.V. PORTELLI: Yes, I agree with you. Jim would like to make a remark.

J.W.S. YOUNG: Based on personal experience in New Brunswick, I had occasion a number of times to review EIS's as a control agent, and in a lot of cases, using the same data set and comparing our results with the model that I believed in with the consultant's work, the answers were totally different. I think there has to be some kind of either a data set or an agreed model that can be compared with all models that are used, and on that basis I'd like to push for say a standardization of at least certain types of models, perhaps supported by AES headquarters, open to everybody, because otherwise provincial governments who don't have the expertise that we have or that consultants have, get tied up in trying to make a decision between two competing experts, and that doesn't work.

R.V. PORTELLI: The question on this next overhead is based on the assumption that a need does exist: "If a need does exist then what type of models are required?" I think maybe before it is discussed openly the next slide might be put over, and these are maybe 1/3 of the difficulties that have arisen that we have not been able to respond to: Requests to provide assistance in coastal fumigation modelling, calm wind conditions, over-water diffusion calculations, and this arises from off-shore nuclear reactors, and incineration at sea operations, ice fog formation from moist plumes. We provide literature, quite often, and that kind of support to our regional people and provincial requests, but we have not got something that we can say here is a model that you can use and maybe could be adapted to the problem. We have had requestes for assessment of airports, one for example was the proposed STOL port at Toronto, and we had to recommend to them to go elsewhere simply because we did not have the capability. Now what we're talking about here is not necessarily the development of new or redundant models which have been developed in the U.S., that would be ridiculous. I think what we're talking about here is for example, airport modelling. The Argonne National Lab have done extensive work in this. I have a copy of their most recent document on a revised airport model. Adapting this to, for example, the Hamilton expansion, when it comes time for us to provide input to the EIS. Otherwise our input to the EIS is simply from the point of view of consultation on paper with respect to what models have been dealt with elsewhere, and our opinion based on that, not our opinion based on actual experience with some of these things. The two other ones that are noted down are complex terrain and urban areas. I think they are long-standing areas of need and concern. Montreal has voiced it's concern for urban models there, and B.C. has often had AES experts from the point of view of mountainous terrain provide consultation, and I believe the group is working towards the development of capabilities in such areas. However, if one needs to apply something in the immediate future, you don't need to develop a new Gaussian valley model; that definitely has to be the case. You can attempt to maybe adapt some of the

existing work that has been done. The UNAMAP series which John (Walmsley) talked about is available to anyone through EPA. Would that be of value to adapt onto a system where it would be centrally administered? What Hugh (Fraser) said was a problem - that if the regions were to try to take on these models and administer them it would be rather difficult, if not impossible, but I think we can illustrate later that this could be circumvented if it is required. Some are leading us to believe that we had better do this. Is there any specific area that would be very high priority that should be addressed in terms of development or adaptation for regional concern, because whether you voice it now or whether you voice it through correspondence, I think it has to be voiced, otherwise we can't really address it, except through our own research efforts or through our own direction.

S. NIKLEVA: Could I just make a comment first on the previous question there; I wasn't suggesting that AES doesn't develop models, I think that we should, and the comment with regard to consultants is really in the application of the model. For example, a consultant might say that here is an AES model, and they apply it to an area where there are terrain effects, this could be applied and the consultant might put in a lot of extra information and then deal with the problems in applying that model, which might make the whole thing acceptable. But then again he might not, so I think that we should develop models and they should be available. It should be just a tool that's available. Now I think it's up to the province and other regulatory agencies to decide which model or technique to apply, in priority areas such as mercury emissions and trace metals, and this is one thing that the models have difficulty handling. The other thing is the question of acid rain, where we're looking at sort of regional distances, maybe not long-range transport as we think of it back here, but long-range transport in the fact that ground level concentration standards can be met, and yet we can still have problem with acid rain.

R.V. PORTELLI: I think we had better press on to what we propose for some of these smaller, simpler problems. As a matter of fact, ever since I began at AES this is the type of system that has been used - it is an interactive modelling system where, for example, the models that you dealt with yesterday in your problem sets would be on a central computer here in Toronto, not at AES unless AES develops a strong interactive capability, but on time-sharing system. They would be on a core area which would not be at cost to anybody but the computer firm, it would be like one of their system files. They could be confined to government people or they could be opened up right across the board. With these models on the system, a simple run command initiates a series of questions from the computer requesting input data (the units and constraints on the type of input data are specified). Once input has been completed, model execution commences and output of results follows immediately. Therefore, if you wanted to run for several meteorological/plant operating conditions to estimate potential concentrations downwind of the plant, this could be done within a short period of time (those who attended yesterday afternoon's workshop saw a demonstration of an interactive model).

Initially, we are recommending this system for simple models only such as the simple short-term point source models you dealt with yesterday, or the longer term simple models. Also routines which were dealt with by F. Fanaki on the various plume rise relationships could be incorporated - they have been modularized so that one could interchange plume rise routines to do intercomparisons. Also, various dispersion coefficient routines are available to carry out this type of exercise. This is useful if for a particular plant in a

specific setting one wishes to compare against the dispersion coefficients from on-site observations. There are also new routines which have been developed. For example, Chuck Matthias had to handle a request on ice fog formation from wet plumes in B.C., and he put together a small package of information and did some rudimentary modelling. That could be turned into a basic modular form so that it could be adapted or applied in other situations.

Now what we're talking about is a foundation of simple models for users; we're not talking about models such as LIRAQ which are extremely complex. That would be ridiculous at this point in time. In my view, we should be carrying out this type of modelling activity and I'm recommending that we consider it within the near future, so that we can provide users with a basic modelling capability. The interactive system that is dealt with in the next slide, illustrates the Canada-wide communications network. This is not to push Dataline. As a matter of fact there are many services such as Dataline. This happens to be one of them, the one that is being used currently. Dataline's computers are in Toronto and the firm would take on the cost of storing such routines or models which can be accessed across the country from standard terminals - the smallest ones are about the size of a 12" x 12" area, which you can carry to a meeting and run from a remote location if necessary. Dataline has direct lines to all the locations shown in Figure 1 and also several support offices. So this would reduce the burden on Downsview if the smaller modelling activities could be handled by the regional people. The use of the system is very simple and the use of the models could be made simple in addition to documentation. (Some models have already been documented and provided to some of you). This is the type of user modelling system that appears to be the best way to go from our view point, and if there are any reactions, we'd appreciate hearing them now.

G. DESAUTELS: I'd like to comment on the cost of lines being so much, and most regions now have got their own minicomputers. That program of yours yesterday seemed to be a pretty small program that could be adapted to most regional computers right across Canada within the weather centres themselves, which most SSU organizations have got access to, and most of them have got modems, which can connect telephone lines to remote meetings and so on. So why Dataline, it is something I don't understand.

R.V. PORTELLI: This is a recommendation as a possible alternative. Ontario region has taken models and dumped them on their computer system. What this obviates is the regional concern of having to maintain the file, maintain the updates, the improved modelling capability, maybe the incorporation of transformation terms, things of this nature, where you would not have to go to six different places, or each region having to do it. It would be done centrally, and you would have that as the most up to date model and you wouldn't have to worry about it. Each time you'd run it you'd be notified of any change. It is similar to the UNAMAP system or any interactive capability where a user just signs on and is told if there has been an update. He doesn't have to worry about actually making the changes and making sure that it's validated over and over again. Now we're talking about some time in the future to get to that point, but that's what it obviates. The cost could be minimal because the run times are small on some of these things.

G. DESAUTELS: Surely you're capable of publishing a newsletter in the form of a magnetic tape where you just dump the source onto the regional computer.

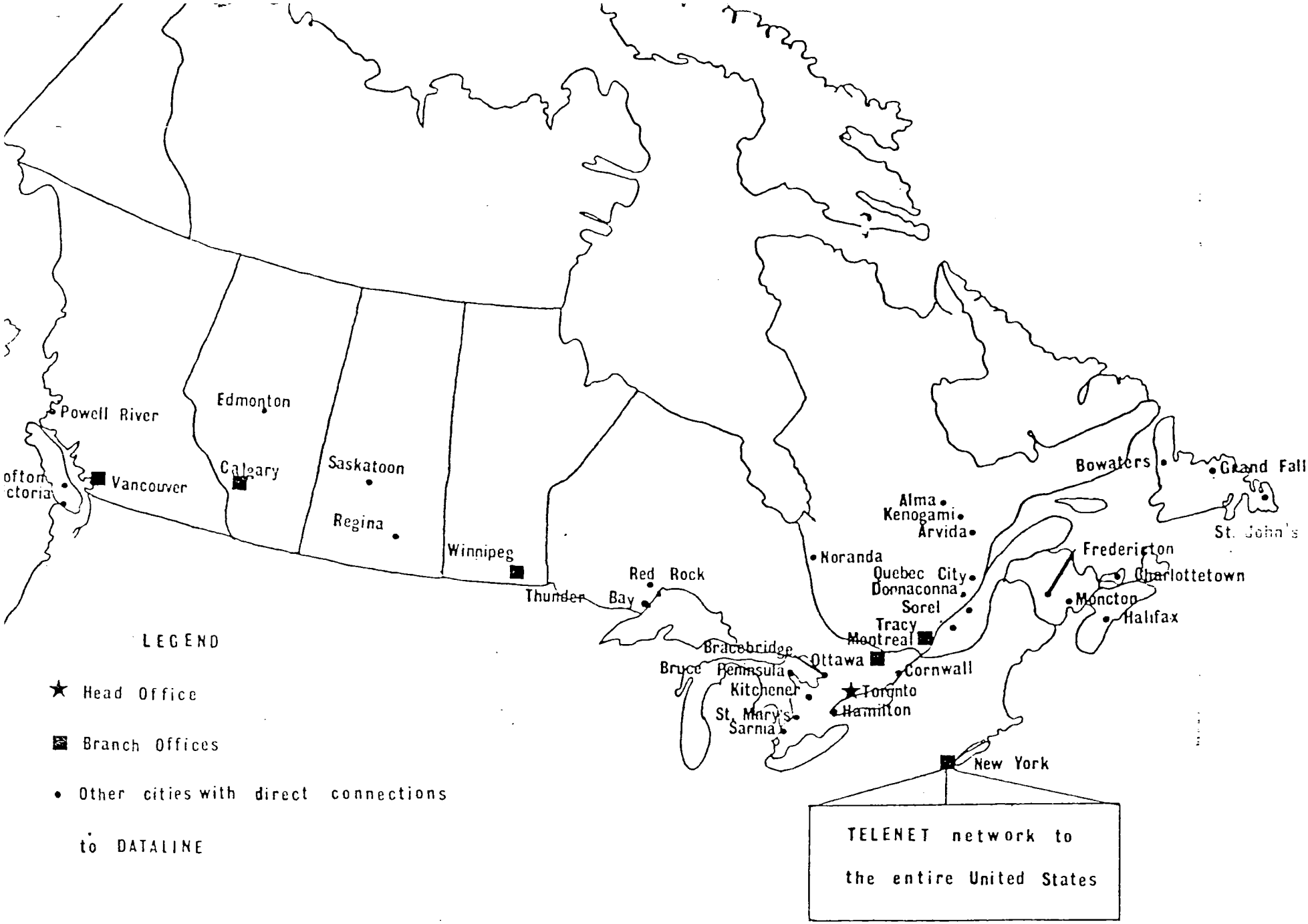

Figure 1.

THE **DATALINE** COMMUNICATIONS NETWORK

J.W.S. YOUNG: There's one other problem, and that's, say, we open this up to outside users like consultants, how do they get hold of it? They can't go through your computer.

G. DESAUTELS: Yes they can, through telephone lines.

R.V. PORTELLI: We'd like some active response to this if there exists some from the regions in terms of writing us and letting us know how you feel about this. Should AES be recommending air quality modelling guidelines - Boris (Weisman) mentioned this. The U.S. put out guidelines, conditions in Canada are somewhat different although quite often the same models are used. It wouldn't mean we'd attempt to generate new and better guidelines than EPA and be in competition with them, but being a national research group in this field, the feeling has been I believe from many, that we should be responsible for providing direction in this regard. Does anyone agree or disagree with this?

J.W.S. YOUNG: I wonder if we could get an overview say, from each of the AES regions on the whole thing we've presented; your feelings about how far we should go, whether we should scrap the whole thing, or what. Ernie, I know you've used a lot of our programs, have you got any comments?

E. BRANDON: Well, I suppose my comment to that one would be somewhat facetious. If AES is not going to recommend air quality modelling, who is?

R.V. PORTELLI: That happens to be my opinion also. In the research group which has historically spent most of its time in let's say not more pure, because it's not really pure either, it's quite applied in a sense, but away from the applications end, I think we have to be careful how we proceed. We've been proceeding on an ad/hoc basis up until now, on a per request basis, and it makes it difficult to plan, it makes it difficult to systematize, and this is all that's being considered now. It is not to create another area to jump into with large resources, but to do it on a systematic basis so that each region has the same capability. Right now two regions have dealt with the models we have, because they requested them. The others haven't so they haven't received them. Should we continue on that basis? We're recommending we don't, and if there's nothing further...

B. WEISMAN: Jim made a comment on this a minute ago. In addition to recommending actual models for assessments, I think somebody should be doing some thinking about what kind of data sets should be used to determine the impact at a particular location, of a new source or urban development or whatever it is, and that there is no guideline as far as I know right now, and one consultant will run a model for three conditions and say that's the story, and another one will go through two years of data, and which one is better; which one would you recommend?

R.V. PORTELLI: That's a very important point. There are current activities within the branch that are trying to provide data sets on meteorological potential for pollution on a climatological basis, and that will be discussed tomorrow.

G.A. McBEAN: I think to stress what Ron commented on at the end there, that it would be useful I think, from the branch's point of view to have some written feedback, maybe when regional people have had a chance to go back and digest or think about this and talk to their colleagues to send in some specific comments in this regard.

FLOW OVER COMPLEX TERRAIN: WIND FIELD MODELS FOR DISPERSION CALCULATIONS

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INTRODUCTION

There is considerable current interest in airflow over complex terrain on a variety of scales and for a variety of reasons. On the global scale mountains and surface temperature inhomogeneities excite Rossby and planetary waves while on the mesoscale there is continuing interest in theoretical and experimental (ALPEX) studies of lee cyclogenesis and fohn winds. Boundary layer specialists have also slowly weaned themselves from the study of horizontally homogeneous, infinite, flat plains to look at flow above changes in roughness, temperature and elevation. Numerical modellers have moved somewhat ahead of comprehensive field experiments at this stage but a few careful, small scale, experiments of boundary-layer flow have been conducted (eg. Peterson et al. (1976)) and others are planned. Much of this work has been motivated, at least partially, by the need for better understanding of atmospheric dispersion but renewed interest in windmills (now called WECS (Wind Energy Conversion Systems)) and plans to site these on the tops of exposed hills has allowed us an additional justification for the recent study of wind flow over hills. (Jackson & Hunt (1975), Taylor (1977a,b))

In the present paper we will concentrate on aspects of modelling flow over complex terrain within an overall horizontal domain of order 100 km x 100 km with a horizontal resolution of 1 - 5 km. The vertical extent of the model may be from about 1.5 - 10 km. For many purposes we are able to use hydrostatic models on these scales while for smaller terrain features (eg. hills of horizontal scale 1 km) non-hydrostatic or dynamic pressures can become important. Models on the smaller scale have tended to concentrate on flow over idealized terrain features,

changes of roughness, idealized bell shaped hills etc. while on the larger scale there has been more attention given to simulating flow over actual terrain.

THREE DIMENSIONAL PRIMITIVE EQUATION MODELS

Perhaps the best known hydrostatic three dimensional boundary-layer model is that developed by Pielke (1974) and Mahrer & Pielke (1975, 1977 a,b, 1978) in a series of papers and applied to areas such as Florida and the island of Barbados. Other workers have modified and extended their model, eg. Yamada (1978), Walmsley and Reid (1976), Walmsley (1978), while a non-hydrostatic model has been used by Tapp and White (1976) in comparison with Mahrer & Pielke's predictions for the Florida sea breeze.

The essential features of the hydrostatic models are that they include predictive equations for the evolution in time of horizontal velocity, temperature and humidity fields. Pressure and vertical velocity are computed diagnostically at each time step from hydrostatic balance and the continuity equation. Turbulent transfers are represented by eddy viscosities and diffusivities, typically separated into a z dependent vertical coefficient, K_z, and a constant horizontal exchange coefficient K_H. In some cases horizontal smoothing is applied to ensure computational stability and, perhaps, to simulate horizontal diffusion.

Considerable caution is required in the treatment of initial and boundary conditions but the models appear capable of generating reasonably realistic wind, temperature and diffusivity fields for subsequent pollutant dispersal calculations. Computer time and space requirements are quite substantial as one typically has about 30 x 30 x 12 or 10^4 grid points at which the 6 variables are defined. With a 20 x 18 x 11 grid Walmsley & Reid (1976) found that each simulated hour of flow development required approximately 2 minutes of computer time on the AES Cyber 76. In most cases on these scales the hydrostatic pressure assumption appears to be acceptable.

A SINGLE LEVEL PRIMITIVE EQUATION MODEL

In an attempt to avoid the computing requirements and complexity of three dimensional models Danard (1977) has developed a single level primitive equation model. Some of this work has been done in collaboration with the Meteorological Services Research Branch of A.E.S. who use the model under the acronym SAM (Small Area Model). Model details are given in the papers by Danard (1977) and Venkatesh and Danard (1978). The model is used diagnostically and attempts to compute surface winds for an area at a given time based on observed or forecast geostrophic winds (sea level and 850 mb), sea level pressure and 850 & 700 mb heights at a single location together with an observed or predicted surface temperature field. Surface elevations and roughnesses for the area are also required.

The basic approach is to integrate forward in (artificial) time from an initial state based on a downward extrapolation of 850 & 700 mb temperatures, with horizontal gradients evaluated via the thermal wind equation, and a surface wind based on a balance between surface stress, coriolis force and initial pressure gradients. Heat is then added to bring the surface temperatures to their observed values while the wind field adjusts to include modified pressure gradients, advection and horizontal diffusion effects.

The model clearly does considerable violence to the physics but appears to give useful predictions of the surface mesoscale wind field provided one is careful to use representative observed winds for comparison. Danard (1977) applied the model to the Juan de Fuca and Georgia Straight area using a 15 x 25 grid with a 10 km spacing while Venkatesh and Danard (1978) used a smaller 10 x 10 grid, again with 10 km spacing for flow predictions over western Lake Ontario during IFYGL. Recently Heimann (1979) has compared results from a slightly modified version of Danard's model (called REWISIM) with observed winds in the region around Frankfurt (F.R.G.) with moderate success.

The SAM or a modification of it will be used as part of the Canadian contribution to Annex II of the International Energy Agency programme of research on site selection for WECS.

INTERPOLATION AND ADJUSTMENT SCHEMES

A fundamental input to a dispersion calculation is the wind field. Unfortunately, it is impracticable at present (even with remote sensing!) to observe winds with the spatial resolution required for input to a model of dispersion in complex terrain. Indeed one is often lucky to have much more than a surface wind at a "nearby" airport. Faced with the problem of generating a three dimensional wind field or two dimensional flux field from, perhaps, half a dozen surface wind and inversion height observations in a $(100\ km)^2$ region one would probably first try interpolation schemes of one sort of another to produce a wind field on a regular grid within the region. A weighted average of observations close to each grid point may be a reasonable first attempt and may prove adequate for Gaussian plume dispersion models (Gifford 1975). Roberts et al (1969) simply used the nearest of eight observing stations in their Chicago air pollution model. If however, the wind field is to be used as input to a model based on the diffusion equation it is of considerable importance that the wind field satisfies conservation of mass. This has been emphasised by Dickerson (1978) and Sherman (1978) who develop interpolated wind field adjustment schemes for use in conjunction with the Lawrence Livermore Laboratories regional air quality models LIRAQ and ADPIC.

The first of these, MASCON (Dickerson (1978)), is quasi two dimensional (x,y) in that it computes mass consistent atmospheric fluxes between the ground and an inversion base from observed horizontal wind (u_o, v_o) and inversion height (h_o) data. Conservation of mass required that

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(hu) + \frac{\partial}{\partial y}(hv) + \omega_h = 0 \qquad (1)$$

at all points in the region considered where u and v are vertically averaged velocities and ω_h is vertical velocity through the inversion height, h. Grid interpolated observed data (subscript o) will not meet this requirement and the purpose of MASCON is to minimally adjust the observations (in a least squares fit sense) to give a mass flux field satisfying (1). Relative magnitudes of adjustments in ω_h and (hu) & (hv) can be chosen to satisfy ones prejudices. Dickerson presents results for the San Francisco Bay area. Initial "errors" in (1), assuming ω_o to be zero, were of order 10^{-1} to 1 ms^{-1} which were reduced to near zero in the adjusted field. There is considerable adjustment to the horizontal flux fields (see Figures 8 and 10 and Figures 12 and 14 (13?) of Dickerson's paper). An essential feature of the 'model' is that it adjusts observed horizontal fluxes to reduce the vertical velocities at the top of the mixed layer that might otherwise be computed from the raw data. There is a degree of arbitrariness in this procedure, as Dickerson acknowledges, which will require improved understanding of entrainment at inversions to resolve, but it clearly useful in preparing mass flux data for mixed layer dispersion models.

MATHEW is a scheme for generating a "mass-adjusted, three dimensional wind field". It uses similar variational techniques to the MASCON model. The basic constraint is that the adjusted wind field should satisfy the continuity equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (2)$$

The initial wind field is usually based on interpolation and extrapolation onto a three dimensional grid from a few (perhaps 10) surface wind observations, a vertical wind profile if available and a synoptic analysis. There is usually no information available on vertical velocities and w_o is set to zero. The adjustment procedure then consists of modifying the initial wind field to minimise

$$\int_V \{\alpha_1(u-u_o)^2 + \alpha_1(v-v_o)^2 + \alpha_2(w-w_o)^2 + \lambda(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z})\} dV \qquad (3)$$

where $\lambda(\underline{x})$ is the Lagrange multiplier and α_1 and α_2 are Gauss precision moduli. The choice of the ratio α_1/α_2, as in MASCON, determines the relative adjustments allowed in horizontal and vertical wind fields. Sherman (1978) chose a value to suppress vertical velocities to a few centimetres/second.

MATHEW has been used in a number of test applications. Sherman (1978) gives results for sites in Idaho and South Carolina while it is also being tested on a data set from Oahu in connection with the U.S. and IEA WECS siting programmes. (Wendell et al (1978)). A modified form of the model using terrain following coordinates, designated NOABL, is under development by Science Application Inc. of La Jolla, while Sklarew (1978) reports on a wind field model (NEWEST) which minimises divergence by an iterative procedure starting from observed winds and estimates of thermally generated perturbation winds.

CONCLUSION

Prediction of the detailed wind field over complex terrain is an extremely difficult problem. The flow is turbulent, and sometimes highly turbulent if for example, the flow separates over a hill. It is modified from that occurring over homogeneous terrain by thermal effects as well as surface topography and roughness. Solution of the primitive equations with suitable turbulence parameterization and the use of the hydrostatic appoximation is possible in principle but one must beware of problems associated with the specification of boundary and initial conditions. As always, the turbulence parameterization will be open to criticism and major programming and computing effort is required. The SAM attempts to reduce this effort at the cost of introducing additional assumptions and approximations.

The interpolation and adjustment schemes described also have major programming and computational requirements and cannot be undertaken lightly. At present they are perhaps the best way to generate wind fields for dispersion models if sufficient data are available. If not it may be possible to use the SAM to gener-

ate the initial wind field for subsequent mass consistent adjustment. In the long term however, one might hope for improvements and developments in the primitive equation models which in theory at least are capable of predicting plume dispersion parameters in addition to the wind field.

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DISCUSSION/COMMENTS

R.V. PORTELLI: What would you say about the limitations of using such models with regard to the constraints for input data? That is one of the major difficulties I see, as you were saying let's get more to the realistic situation and put a few more stations in; I'd suggest the more realistic situation might be the reverse, that there would be fewer stations for the data, and secondly, what would be the possibilities in your mind of going to remotely sensed data as input to such models?

P.A. TAYLOR: I don't really know how to answer that. As far as remote sensing is concerned, certainly there is a lot of potential there. Acoustic sounders now seem to have the capability to give you reasonable horizontal wind fields in the boundary-layer, the sort of systems that they have at Penn State seem to perform well. On the other hand, they are relatively expensive, and if you want to talk in terms of having 50 of these around the area that you're concerned with then it becomes prohibitive. As far as the use of these interpolation schemes in dispersion models is concerned, perhaps it doesn't really matter very much that they produce wind fields which aren't all that accurate, as long as they don't violate the physics too dramatically.

S. DAGGUPATY: I would appreciate it if you could clarify the equation of continuity used in MASCON and MATHEW. If I am correct, they are using the incompressibility form, where they're not taking care of the density gradient to get the winds. How close is this to the truth when you consider the sea breeze where over-land temperature differences are important? Do you think incompressibility in the boundary layer is valid? I suspect they should be using the full continuity equation.

P.A. TAYLOR: It depends on the vertical excursion of an air parcel, and in the main, this is relatively small, and you don't have to worry about variations.

S. DAGGUPATY: Is this time in the sea breeze situation?

P.A. TAYLOR: Well, in principle you could apply the model using the inelastic approximation rather than the incompressible equation, but I don't think that would alter the philosophy behind the model.

NON-GAUSSIAN AIR QUALITY MODELS

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INTRODUCTION

When dealing with non-reactive pollutants over fairly uniform terrain the Gaussian model approach described in previous presentations has proven remarkably successful in handling air quality assessment problems. In fact, its range of useful validity has proven to be far wider than one would assume from conventional theoretical arguments. This is fortunate since the input data and computational requirements for most non-Gaussian models are much larger than for the Gaussian. However, there are occasions when the Gaussian approach fails to give satisfactory predictions and other approaches may be useful.

The point of departure for most non-Gaussian models (and leaving aside any consideration of strictly statistical models) is the Reynolds' averaged form of the conservation of species equation for non-divergent mean flow:

$$\frac{\partial \overline{\chi}_i}{\partial t} + \overline{U}_\alpha \frac{\partial \overline{\chi}_i}{\partial x_\alpha} = - \frac{\partial}{\partial x_\alpha} \left(\overline{u'_\alpha \chi'_i}\right) + S_i \qquad (1)$$

where

$\overline{\chi}_i$ is ensemble average species i concentration at a particular point,

$\overline{U}_\alpha$ is the non-divergent mean wind speed in the x_α direction at a particular point,

$\overline{u'_\alpha \chi'_i}$ is the ensemble mean product of wind speed in the x_α direction and species i concentration fluctuations at a particular point.

S_i is a term representing source, depletion and transformation process effects on species i concentration at a particular point.

This formalism becomes useful when assumptions applicable for particular cases can be introduced which reduce the complexity. The skill in non-Gaussian air pollution modelling comes in implementing the greatest simplification appropriate for the particular problem of concern. The remainder of this paper is devoted to the presentation of a few examples of such simplifications and some discussion of implementation, or implementation potential, in Canada.

BOX MODELS

Perhaps the simplest type of air quality model, simpler than even the Gaussian, is the box model. A particular atmosphere volume of concern is selected, normally bounded aloft by an inversion, and the mass budget(s) of the pollutant specie(s) of concern are computed. Mathematically the model may be derived by integrating the species conservation equation over the region of concern. Two particular choices of box are in common use.

In the Eulerian Box formulation the box is fixed in space. A common assumption is that the pollutant is well mixed in the box, although in some versions a vertical concentration profile is permitted. In the general case advection through the sides of a box can be large and the well mixed assumption leads to poor estimates of this term, as pointed out by Venkatram (1978). However, the model is particularly useful in cases where such fluxes across the boundary may be ignored. This occurs where the sides of the box may be specified by physical features such as the walls of a mountain valley or an indoor parking garage. A useful basic reference for this type model is Stearn (1968), while Ragland (1973) is a study using multiple adjacent Eulerian boxes with allowance for vertical variation of concentration.

In the Lagrangian box model the box is assumed to be advected about with the mean mixed layer wind. Thus there is no mean air transport through the sides of the box, only transport

due to eddies. Although the eddy transport cannot normally be neglected, over large cities, or for emissions from a forest, which may be considered as large area pollution sources, local pollution concentration gradients are small. In these cases a Lagrangian box has negligible net eddy transports across its faces. Liu and Seinfeld (1974) assessed errors in this model and found the most significant was the neglect of effects of vertical wind shear which in reality deforms the box with time. Some examples of application of the Lagrangian box model, although in a somewhat disguised form, are the application by Summers (1965) to Montreal, Leahey (1972) to New York, Leahey (1973) to Edmonton.

LIRAQ

The Livermore Regional Air Quality (LIRAQ) model was developed by scientists at Lawrence Livermore Laboratory for the study of time - dependent regional air quality in the San Francisco Bay Area. Regional pollution in the area is characterized by the influences of complex topography, frequent capping inversions, numerous pollutant sources (area,line and point) and important photochemical pollutant transformations.

As shown in figure 1, the model system runs interactively with an operator at a teletype station. The operator forms model input files for the scenario of interest from a data library of topography (QGEO), source emissions (QSOR), meteorology (QTRAN, as formulated by MASCON), initial pollution concentrations (QICON, or QREST) along with run data. The model simulates the temporal and spatial evolution of pollutant concentration on a two-dimensional horizontal grid. Physical processes of concern in LIRAQ-1 are horizontal and vertical advection, sub-grid scale eddy transports, deposition at the surface, simple species decay and pollutant source emissions. A more complex version, LIRAQ-2, also handles pollutant photochemistry.

Two critical assumptions are made in the formulation of LIRAQ. Firstly, it is assumed that there is no effect of air

quality on the meteorological fields beyond that contained in the meteorological observations. This simplification allows an independent analysis of the meteorological fields to be made and then applied to different emission scenarios. In this way the treatment of the meteorological fields is diagnostic, while that of the pollution fields is predictive. The second major assumption is that only a single vertical layer, between the surface and an elevated inversion, is treated. The height of the surface can change due to topography and the inversion height is allowed to change with space and time as given by MASCON. Because an elevated inversion is a common occurrence in the Bay Area for conditions of region air quality concern this is an appropriate and useful assumption there but may not be the case elsewhere.

The model equations are derived by integrating the species conservation equation from inversion height down to the surface (actually to a reference height which is typically observation height). This is done by assuming functional forms for the wind and species concentration vertical profiles.

$$u(x,y,z,t) = u_o(x,y,z_o,t) \left(\frac{z}{z_o}\right)^n \qquad (2)$$

and

$$\chi(x,y,z,t) = a(x,y,t) + b(x,y,t) \ln \left(\frac{z}{z_o}\right) \qquad (3)$$

The a and b coefficients above are determined by constraints imposed by the surface pollution source and sink rates and the requirement that the vertical integral of concentration below the inversion be equivalent to the average value calculated using the integrated form of the species conservation equation. It should be noted that the logarithmic form of the concentration profile is strictly incompatible with elevated sources since the logarithmic form must have the maximum value either at the surface or inversion level. Emissions from elevated sources are assumed to affect only the vertically averaged concentration, effectively assuming a rapid vertical mixing of

elevated source emissions. A similar horizontal smoothing is implicit because of the limited horizontal resolution.

LIRAQ is applied on a finite difference grid, up to a maximum of 45 X 50 grid elements, with typically 1 - 5 km grid spacing. In solving the governing equations the horizontal advection terms are treated first using a two-stage flux corrected transport algorithm. Then the horizontal eddy fluxes are computed using a second-order diffusive velocity prescription. Thirdly transport through the inversion, based upon airflow computed by MASCON and inversion level concentration is determined. Finally, effects of decay, deposition and source emissions are computed.

Two versions of photochemical submodels have been employed, LIRAQ-2 treats 16 inorganic species and 3 classes of organic compounds. In the more recent LIRAQ-2S a simple homogenous scheme for sulphur chemistry is added. Adding atmospheric chemistry greatly increases the complexity of the computations, not only because a large number of chemical reactions have to be computed at each grid-point (there are 48 reactions in the LIRAQ-2 set) but also because of the wide range of associated characteristic time scales. To meet these demands the domain size and sophistication of the finite differencing are reduced from LIRAQ-1.

One of the major problems in applying this type of model is the prodigious initialization data requirement. At each grid point initial concentrations for each pollutant species, an emission inventory valid through the run period, and meteorological data from MASCON are required. In addition coefficients for various parameterizations (roughness lengths, deposition velocities, etc.) are required.

At Lawrence Livermore Laboratory (LLL) LIRAQ-1 runs on a CDC 7600 requiring typically 47K Small Core Memory, 400K Large Core Memory and 2MW disk storage operating on a 45 X 50 grid element array. With 2 pollutants and a 24 hour simulation the run time is about 55 minutes. The run time for LIRAQ-2 is not greatly different because of simplifications in the finite

differencing and reduced grid size. A typical example of a computed concentration field from LIRAQ-2 is shown in figure 2.

For more detail on LIRAQ see the journal paper by MacCracken et al (1978), the more complete development reports, MacCracken and Sauter (1975), and the users guide MacCracken (1975). Reid et al (1979), in press, review LIRAQ (as well as MASCON, MATHEW, ADPIC and PATRIC) for AOSERP application.

ADPIC

The Atmospheric Diffusion Particle-in-Cell (ADPIC) code is a numerical three-dimensional, Cartesian, particle diffusion code capable of simulating the time-dependent distribution of air pollutants under many conditions. The code solves the three-dimensional species conservation equation (1) in its flux conservative form (the pseudo-velocity technique), for a non-divergent mean wind field provided by MATHEW. The method is based on the particle-in-cell approach with the pollutant concentration represented by Lagrangian marker particles, each representing a certain mass of pollutant, inside a fixed Eulerian grid. Concentration within a grid cell is thus proportional to the number of markers divided by the grid cell volume.

Equation (1) can be written with the eddy diffusion formulation for the eddy flux form

$$\frac{\partial \overline{\chi}}{\partial t} + \overline{U}_\alpha \frac{\partial \overline{\chi}}{\partial x_\alpha} = \frac{\partial}{\partial x_\alpha}\left(K_{\alpha i}\frac{\partial \overline{\chi}}{\partial x_i}\right) \qquad (4)$$

because $\overline{U}_\alpha$ is a non-divergent field the second term may be written $\frac{\partial \overline{\chi}\overline{U}_\alpha}{\partial x_\alpha}$, and this term combined with the last to yield

$$\frac{\partial \overline{\chi}}{\partial t} = -\frac{\partial}{\partial x_\alpha}\left[\overline{\chi}\left(\overline{U}_\alpha - \frac{K_{\alpha i}\partial \overline{\chi}}{\overline{\chi}\partial x_i}\right)\right] \qquad (5)$$

The term in the inner brackets is a pseudo-transport velocity accounting for both advection and diffusion effects.

A time cycle of the code involves two phases. First

an Eulerian step; with the domain divided into cells the concentration in adjacent cells is used to compute the diffusion components of the pseudo-transport velocity at the corners of each cell. This is added to the appropriate mean wind from MATHEW to yield a pseudo-transport velocity at each cell corner. The second step is a Lagrangian step; each marker particle is transported for one time-step with the pseudo-transport velocity obtained by interpolation between the velocities at its enclosing cell corners. A new marker co-ordinate is found by forward differencing. Finally a new concentration distribution is calculated from the new particle positions.

The required eddy diffusivities (K's) can be specified in several ways; different prescriptions have been employed in different applications. One formula quoted by Lange (1978) for the horizontal component under Pasquill C category conditions is

$$K_h\ (t) = \frac{1}{2}\frac{d(\sigma_y^2(t))}{dt} = \bar{U}\sigma_y \frac{d\sigma_y}{dx} \qquad (6)$$

with

$$\sigma_y = 0.17x^{0.92}$$

The vertical diffusion coefficient used was

$$K_z = \begin{cases} 0.1z & 0 \leq z \leq 100\text{m} \\ 10 & z > 100\text{m} \end{cases} \qquad (7)$$

Lange gives an example of a regional study over a 100km X 100km domain incorporating topography and three different continuous sources in which 24,000 cells (40 X 40 in the horizontal, 15 in the vertical) were employed with up to 30,000 particles simultaneously present in the grid. About 90% of the CDC 7600 LCM was required and the model ran about 50 times faster than real time. A typical example of model output is shown in figure 3. Emissions from three sources give the marker plume patterns at 1200 and 1300 EST showing the significant influence of a wind shift.

PATRIC

The Particle Trajectory in Cell (PATRIC) code was developed as a simplified and speeded up version of ADPIC. PATRIC differs from ADPIC in treating only flat topography. The wind-field is obtained by direct interpolation of station values rather than a relaxation model such as MATHEW. A final simplification is that the diffusivity part of the pseudo-transport velocity ($\vec{U}_D$) is computed so that the pollutant distribution diffuses in time as if the distribution were Gaussian. Lange (1978b) shows that for this case

$$U_D = K_x \frac{x}{\sigma_x^2} , \quad V_D = K_y \frac{y}{\sigma_y^2} , \quad W_D = K_z \frac{z}{\sigma_z^2}$$

where σ_x, σ_y, σ_z are the standard deviations, and x, y, z are the distances from the centre of the distribution along the co-ordinate axes. The specification of the K's is dependent upon the emission, continuous or puff, as detailed by Lange. These simplifications permit PATRIC to run much more rapidly than ADPIC. To simulate 1 day on the LLL CDC 7600 computer might take 1 minute computer time. The model has been implemented to run for real time accidental emissions and was used, for example, in predicting radioactive emission trajectories and concentrations for the crash of the Russian satellite in the NWT in 1978.

IMPACT

The air quality model IMPACT (Integrated Model of Plumes and Atmospherics in Complex Terrain) is under continuing development by a California company, Form and Substance, Inc. To this author's knowledge it is the only non-Gaussian model (aside from box models) which are actively being employed in the Canadian consulting industry. ENVIROCON in Vancouver is apparently about to start use of IMPACT for an assessment of some radioactive emissions in the interior of B.C. There are also plans by the same company to use the model for a study in

Bedford Basin. B.C. Hydro apparently also has a version of IMPACT available, although it is not presently in use.

IMPACT consists of an airflow model based on the constraint of non-divergence of the flow, but also incorporating some additional "heuristic" constraints on stability damping of vertical velocity and up- or down-slope wind proportional to horizontal (free atmosphere to mountain) surface temperature differential. The solution of the three-dimensional conservation of species equation is performed on an Eulerian grid. Sklarew and Tran (1978) state that the solution is performed by splitting the transport, solving separately in each direction, utilizing a second-order flux-corrected finite-difference algorithm. Unfortunately, these authors fail to enlarge on this description.

CANADIAN PROSPECTS

Aside from box-trajectory models there is currently no operational non-Gaussian air quality assessment model capability within AES. One suggestion often made is that we implement the LLL models as is on the CMC CDC 7600. A major obstacle exists however in the difference in the two 7600 computer systems which may be compared via the following table:

System	SCM	LCM	O/S	Performance
LLL	65 KW	512 KW	TS	1.5
CMC	32 KW	256 KW	RB	1.0

The LLL system has twice the memory of the CMC system and runs a time sharing (TS) operating system as opposed to the CMC remote batch (RB) operating system. This means that, in terms of overall processing capability, the LLL system can carry 50% more load than the CMC system.

The operating systems in use on the 7600's affect the amounts of memory available to user programs. The following table compares the user available memory of the LLL and CMC

systems.

System	SCM	LCM
LLL	57 KW	490 KW
CMC	25 KW	125 KW

As can be seen, programmers at LLL have much more available memory than available at CMC.

A final factor affecting machine performance on the 7600 type of computer is the type of disk system used for system mass storage. The disk system characteristics can be discussed in terms of capacity, access time and transfer rate from disk to memory. For the purposes of the LLL air quality models, both CMC and LLL have more than adequate available on line disk storage. Disk access time is not highly variable between the various types of disk that can be used on the 7600, however, the nature of the physical disk subsystem can affect the performance of the disks by a factor of 2 or more. All LLL disks are dual access configuration type 817 or type 819 disks. At CMC the disk system is implemented for operational use on the Lawrence Berkley Laboratory 7600 system (LBL) using 817 type disks so that quoted machine times for this model incorporate a factor for disk access that has double the possible CMC performance.

The transfer rates of the various disk types are as follows:

Type	844	817	819
Rate Ratio	1.0	6.0	4.0

The transfer rate has a strong influence on operating system performance in terms of job throughout, and a drastic affect on the time required to execute an input/output bound program. As implemented on the LLL and LBL computer systems, the air quality models are not input/output bound models. They make use of the available memory to hold all the required data in memory,

using the disks for input data files and output of results. If these models were to be implemented at CMC, they would require the use of disks for intermediate working storage, thus boosting the required machine time for program execution by a factor of about 10. Reformulating one of the models to employ the intermediate disk storage would in itself demand perhaps of the order one man-year of skilled programmer-analyst time.

Research studies ongoing in ARQB may lead toward development of a particle-in-cell type model for operational AES application. No committments for the development have been made.

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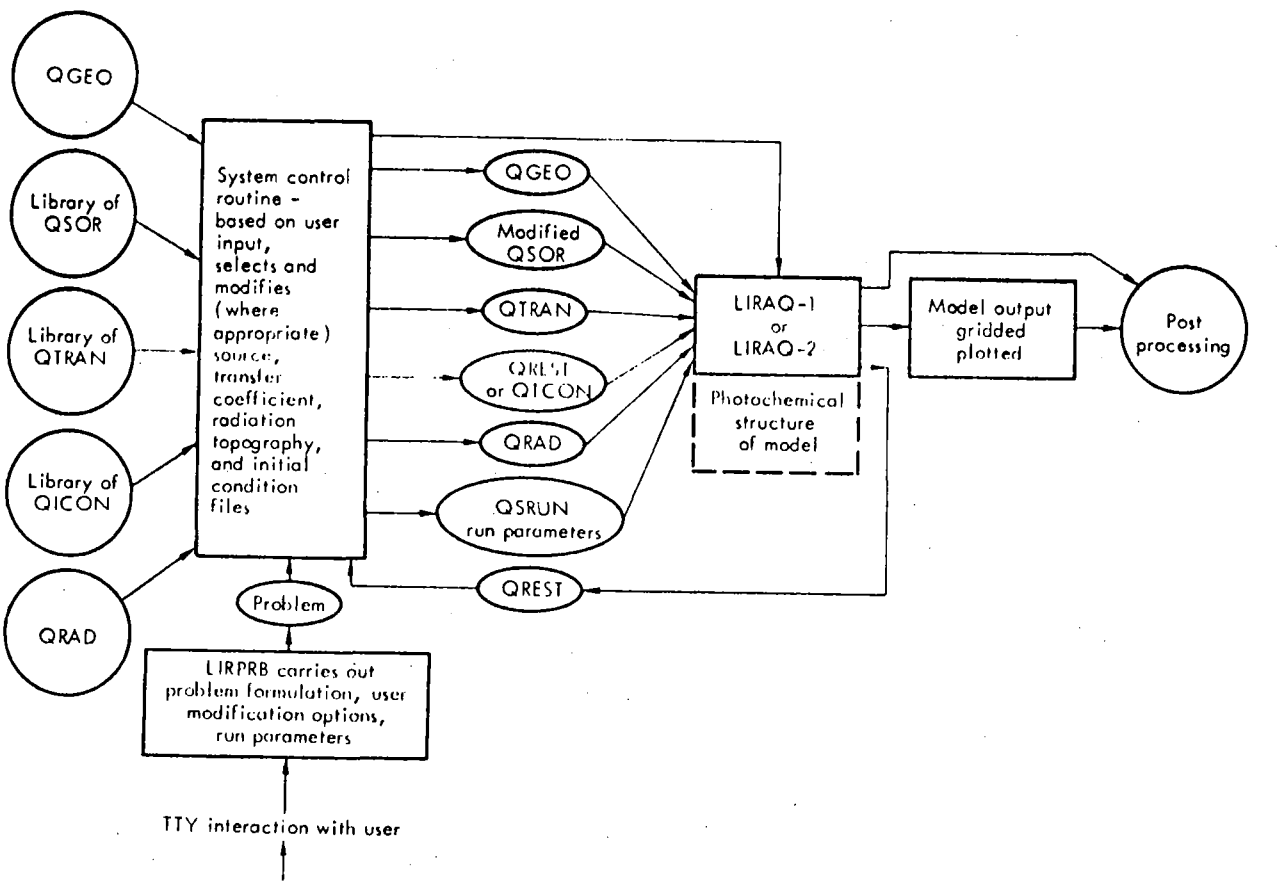

Figure 1: Schematic representation of the operation of LIRAQ.

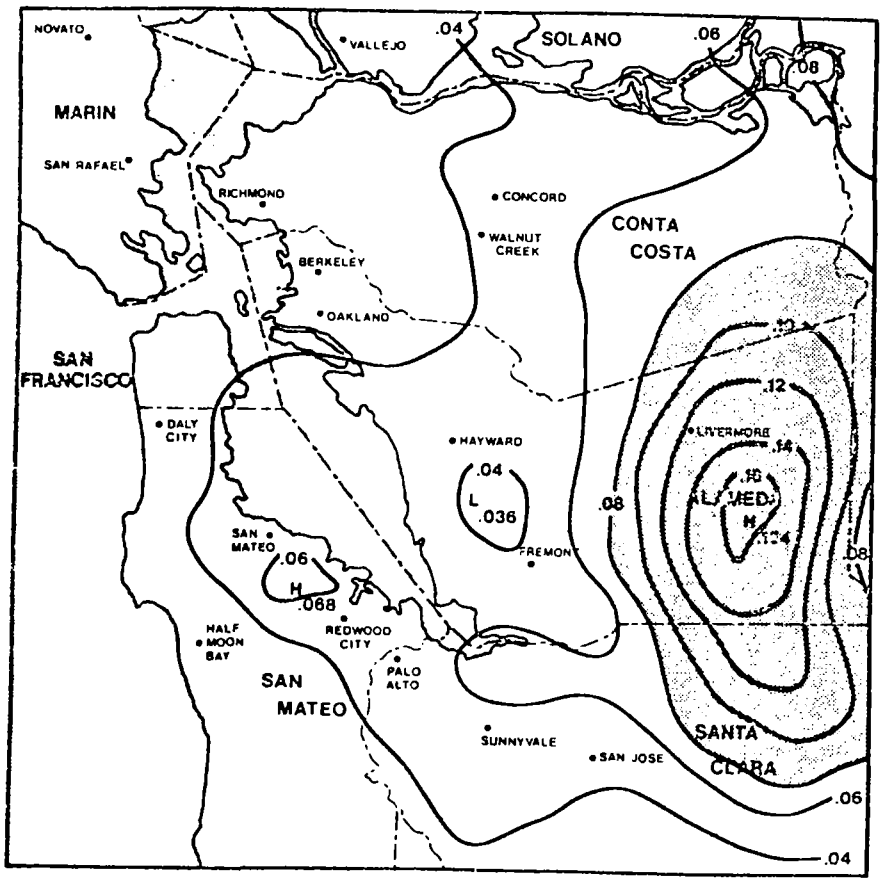

Figure 2: Example of a LIRAQ 2 prediction of ozone conc.

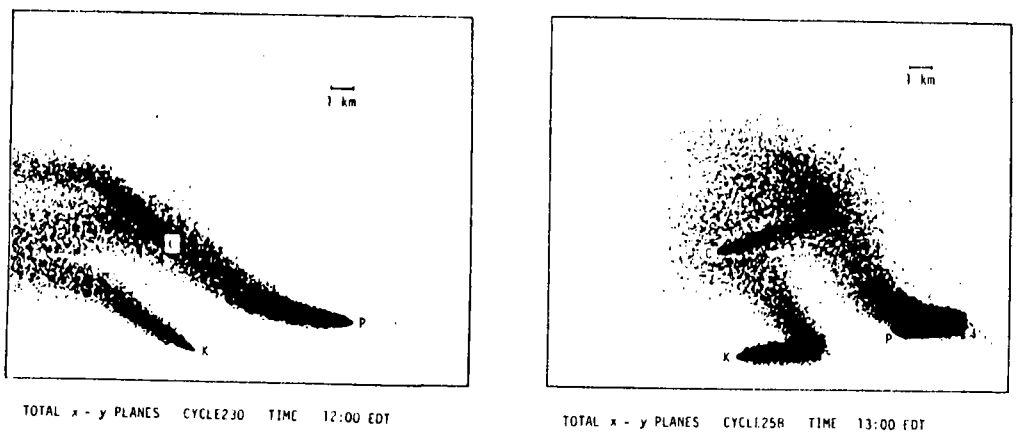

Figure 3: Example of an ADPIC prediction, after Lange(1978).

DISCUSSION/COMMENTS

J. BOBER: - question not recorded

J.D. REID: Well maybe I could just repeat the question. The question was with respect to the types of time and computer requirements to run the IMPACT model. No, I can't give you much enlightenment about that. I did ask the fellow at Envirocon, who I spoke to about this, and he did say that they would be running the model on an IBM 360 or 370 computer, but I would suspect that the analysis times, just off the top of my head, would be similar to that, say for MASCON - 1 minute for analysis. I don't really have a very good feel for the time for the air quality part of the model itself, except if you take 55 minutes per day for LIRAQ (they only run this thing for an hour or so), so you can divide that by 24 and get that they're going to be running a couple of minutes or so. I'm not sure that again, that short time frame really doesn't allow you to bring out the real attributes and beauty of a Non-Gaussian model.

R. GILBERT: In the LIRAQ model the horizontal transfer equation field Kx and Ky is derived from the adjusted wind field and inversion height coming from MASCON. Could you comment a bit on the parameterization of those K's on v and h, please.

J.D. REID: You're talking about the Ky and Kx parameters, I guess Ky particularly that are being used in the LIRAQ model. Now, as I recall it, they are not based on the analysis from MASCON. They are specified in terms of local surface wind and local surface roughness. Just generally, I think one of the parameters I feel least comfortable about, and it is a diffusivity type parameterization, is Ky and Kz, particularly because many of the finite difference methods that I use also have built-in artificial diffusion, which in some cases can swamp the explicit diffusion that's put in. It becomes less significant when you're dealing with regional problems, because the movement of the pollutant to an area is really dominated by the advective wind, and not really by the diffusive component. That's why it's applied in the urban situations.

R.V. PORTELLI: With respect to interactive computer system; you can see that they use it down there, and (J.V. Dave) this morning mentioned the use of interactive capability. I recommended that this is the way that we should all be going. The question is that now that you have introduced these series of models and indicated the complexity of them for our usage, what do you recommend air quality modelling experts in AES direct themselves toward, development or adaptation?

J.D. REID: Well, you'll be pleased to hear that the first thing I recommend is that we make the utmost use of the simple models that are around, the Gaussian model and also the Box model; I don't know that the Box model has really been given as much prominence and it does have a considerable utility. I feel that we should because I think the next computer we get at CMC is going to be a vector machine and particle and cell models can run quite efficiently on vector machines. I think it is certainly time we started thinking about developing something like that to be ready for that sort of machine's capabilities. In the meantime I think we can do some development of a puff grid type model, where the puff would expand in a Gaussian mode, but we would be able to put in the variation of the mean wind fields from something like the SAM model or the MASCON model.

R.V. PORTELLI: I believe INTERA (Consultants, Calgary) uses a potential flow model, maybe similar to the one you've just identified, which is quite removed from the Gaussian types that we've been using.

W.H. SCHROEDER: Are there any constraints on the dimensions of the box models, that is either minimum or maximum box size, on the box models that you've been describing here?

J.D. REID: Well, they're normally applied to situations where vertically you're restricted beneath capping inversion. This is because there is an obvious discontinuity in most cases between rather clean air above the inversion and rather polluted air below the inversion. As far as horizontal dimensions are concerned, there is the problem with the Eulerian model of material being advected through the side of the box, if you're sort of applying it to something like a city where you just sit the box over a particular area, and that is a fairly difficult thing to quantify. There's an interesting paper by Venkatram less than a year ago, I guess, in Atmospheric Environment, where he looks at the errors of the box model, and advocates the Eulerian box model and advocates the Lagrangian box model. I don't know that I can give you a simple answer to your question.

LONG-RANGE TRANSPORT: TRAJECTORY MODELLING

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INTRODUCTION

Trajectories are used in the Long-Range Transport of Air Pollutants project (LRTAP) as a means of tracing the paths of air parcels toward specific measuring sites or away from particular sources. In this way, it can be determined approximately which areas the air parcels traversed enroute to or away from the specific site and how fast the parcels were moving. Often a correlation can be made between the measurement of a pollution episode and the passage of the air over regions of high pollutant emissions particularly if the parcels moved slowly through the area with a short travel time between the area and the receptor site. If trajectories are calculated at several levels in a well-mixed boundary layer, (i.e.) between the mixing height and the ground, then the important effects of vertical wind shear can be included in the analysis of the pollution episode. This type of trajectory information can be used to calculate concentration and deposition values of various pollutants not only at measurement sites but at other locations where no measurements are available.

MODEL DESCRIPTION

There are many approaches to the trajectory computation problem, some of which are discussed in papers by: Eliassen (1) Heffter and Taylor (3), Hoecker (4) and Reap (8). Our trajectory model is similar in concept to Eliassen's NILU model in which successive approximations, within specified limits, are made to the trajectory end-point positions.

The generalized trajectory equation for the movement of a non-interactive air parcel can be written (6):

$$\frac{dX}{dt} = \bar{U} \qquad 1.$$

where $X \equiv (x, y, p)$ and $\overline{U} \equiv (\overline{u}, \overline{v}, \overline{\omega})$.
The finite difference form of equation 1. in forward (or backward) time-step representation is given by:

$$\Delta X = \overline{U}\,\Delta t \quad \text{or} \quad X_f = X_i \pm \overline{U}\,\Delta t \qquad 2.$$

where: X_i is the initial parcel position,

X_f is the final parcel position,

Δt is the time-step length,

and $\overline{U}$ is the mean wind during the time Δt. The $\pm$ sign represents forward or backward motion respectively. The determination of a representative mean wind is the most difficult part of the trajectory scheme.

In the current model, the mean wind $\overline{U}$ is represented as the average wind speed of each component (u, v, ω) between the initial and final position of the parcel and is equivalent to assuming a constant acceleration (or deceleration) during the time Δt ie. $\left(\frac{d^2X}{dt^2} = A\right)$.

Equation 2. can then be rewritten as:

$$X_f = X_i + \frac{(U_f + U_i)}{2}(\Delta t) \qquad 3.$$

The final position X_f is determined by solving equation 3. in several stages.

The first step, which in some models is the only step, is to assume persistence of the initial wind during the time Δt and consequently $U_f = U_i$. Equation 3. becomes in simpler notation:

$$X_1 = X_o + U_o \Delta t$$

The second step is to calculate the wind U_1 at X_1 at time $t + \Delta t$ by interpolating the CMC analyzed wind fields which are normally 6 or 12 hours apart. The wind U_1 is substituted into equation 3. which is solved again to give:

$$X_2 = X_o + \frac{(U_1 + U_o)}{2}(\Delta t)$$

If $(X_2 - X_1)$ is within a given limit, which is currently 0.01 grid lengths, then X_2 is the final position and $(U_1 + U_o)/2$ is the representative wind speed during the time interval Δt which is normally 3 or 6 hours.

If $(X_2 - X_1)$ is greater than the limit, another step is begun in which a new wind U_2 is calculated at X_2 and substituted into equation 3. The new position X_3 is then compared to X_2. The process is repeated until $X_{n+1} - X_n \leq 0.01$ grid lengths and the representative wind speed is $(U_n + U_o)/2$.

These steps are applied to the two horizontal wind components u and v and also to the vertical wind speed ω (ie. $dp/dt = \omega$ mb/hr) where the vertical convergence limit is $p_{n+1} - p_n \leq 1$ mb.

The final points (x_f, y_f, p_f) become the initial points for the next time step and the entire iterative procedure is repeated until a series of end points (x, y, p) have been computed for every time-step along the trajectory which may have a duration of 2 to 4 days. A receptor or source location may be represented by several points, some of which could be above the site as well as a point at the ground (ie. 1000, 925, 850 mb or 0, 500, 1000 m). If no vertical motions are used, the trajectories are isobaric.

HORIZONTAL WIND ANALYSES

The wind fields used to determine the trajectories have been objectively analyzed from the observed data onto a hemispheric, polar stereographic 381 km grid at the Canadian Meteorological Centre (CMC). The analyzed u and v wind components are available at the normal pressure levels (1000, 850, 700, 500 mb etc.) and at 6 hour intervals. The model retrieves wind data from the 1000, 850, 700 and 500 mb levels and uses cubic interpolation to compute wind values at intermediate levels such as 925 mb or 800 mb or wherever the air parcel is located. If the model time-step is less than the wind analysis interval, then quadratic time interpolation is used to approximate the non-linear time variations in the wind fields. Hori-

zontal bilinear interpolation is sufficient to determine the winds at inter-grid point positions. The model has the capability of cubically interpolating the winds from the 381 km grid to a 127 km grid for finer scale analysis.

LOW LEVEL FRICTIONAL TURNING

Since there is an occasional lack of observed wind data at the 1000 mb level, the geostrophic assumption has a strong influence on the wind analysis and a frictional turning term is applied to the 1000 mb wind components to take partial account of the ageostrophic or cross-isobar flow. The analyzed 1000 mb wind components (u_g, v_g) are modified to produce new balanced wind components (u and v). The unaccelerated momentum equations including the frictional stress terms can be written (5, 6):

$$u = u_g - av \quad \text{and} \quad v = v_g + au \qquad 4.$$

or

$$(1 + a^2)u = u_g - av_g \quad \text{and} \quad (1 + a^2)v = v_g + au_g$$

The turning parameter "a" is given by:

$$a = \frac{C_D|V|}{fZ} \quad \text{and} \quad a\sqrt{1 + a^2} = \frac{C_D|V_g|}{fZ} \qquad 5.$$

where: C_D is the Cressman drag coefficient and has a value of about 0.0015 over flat land,

f is the Coriolis parameter,

Z is the thickness of the friction layer and is taken to be about 500 m,

$|V|$ is the magnitude of the balanced wind, and

$|V_g|$ is the magnitude of the analyzed or near geostrophic 1000 mb wind.

Since $|V_g|$ can be computed from the analyzed wind components, the turning parameter "a" can be calculated from equation 5. and the balanced winds u and v can be computed from equation 4. The balanced wind components are used in the trajectory equation 3. at the 1000 mb or surface level.

VERTICAL MOTION

To simulate the ascent of air parcels in low pressure systems and descent in high pressure systems, grid-point fields of vertical motion (ω) are computed every 6 hours by solving the "omega" equation using the Haltiner technique at the 850, 700 and 500 mb levels (2). In our estimation, the method adequately represents atmospheric vertical motions and allows air parcels to rise and fall through changing wind regimes which permit the important and substantial influence of vertical wind shear to affect the parcel trajectory. Vertical motions near ground level are calculated using a terrain pressure field to compute the mountain-induced vertical motion and the Cressman drag coefficient (C_D) to compute the friction-induced vertical motion. The four levels of vertical motion permit cubic interpolation of a vertical motion value to whatever height (pressure) the air parcel may have reached as determined by the solution of the vertical motion form of equation 3. (ie. $\Delta p = \overline{\omega}\Delta t$).

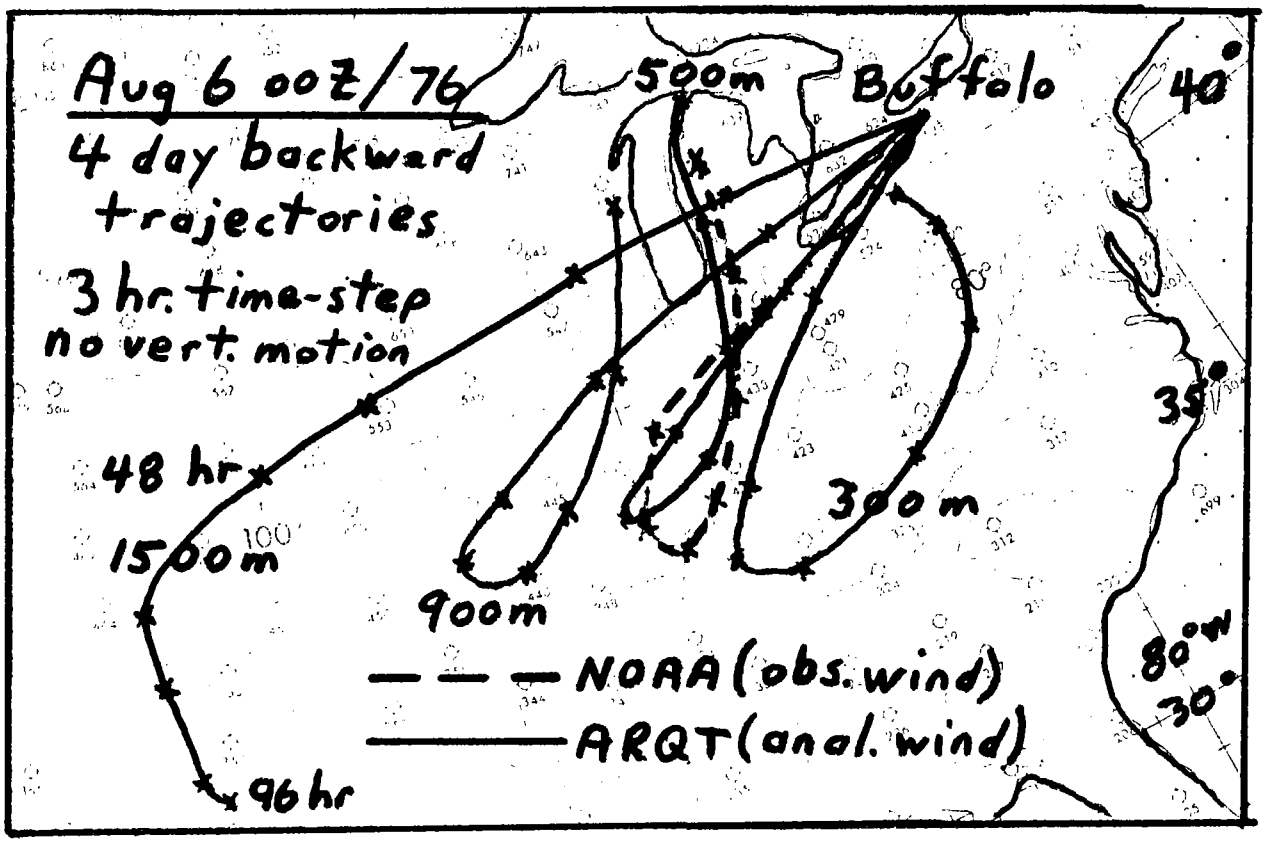

Figure 1. Backward trajectory comparison between ARQT model and trajectory computed by Heffter and Taylor's model (3, personal communication).

CASE STUDY: "NOAA" MODEL AND "ARQT" MODEL

Another form of trajectory model is the "NOAA" model devised by Heffter and Taylor (3). It is a layer-averaged model in which the wind data between 300 m and 1500 m from radiosonde stations surrounding the trajectory end-point are weighted and averaged to produce a layer-averaged wind speed and direction. The resulting average wind is used to compute the next trajectory end-point and the wind is assumed to be

constant throughout the model time-step. The wind averaging process is repeated at each end-point of the entire trajectory so that the trajectory is not defined at a certain level but only within a given layer. Figure 1 shows an attempt to reproduce the backward NOAA track from Buffalo for August 6 00Z/76 by running our ARQT model backwards at several levels within the NOAA model layer. The ARQT trajectory at 500 m very closely resembles the NOAA track. The trajectories at the other three levels vividly indicate the significance of the vertical wind shear which exists in the boundary layer and they demonstrate the effectiveness of a multi-level trajectory model in pollution episode analysis.

CASE STUDY: INTENSIVE SULPHATE STUDY

During August 1976, the Atmospheric Environment Service and the Environment Protection Service conducted an Intensive Sulphate Study (ISS) at 36 stations throughout Eastern Canada (10). The sulphate measurements which were taken at each station indicated the occurrence of several sulphate concentration maxima and minima during the month. Some backward trajectories on a 127 km grid-length scale are shown in Figure 2 from Armstrong, Mount Forest and Halifax at the time of a concentration minimum (Aug. 8-9/76 GMT) and a concentration maximum (Aug. 11-14/76 GMT). The tracks associated with the minimum concentration measurements are generally from a northerly or over-water direction while those associated with the concentration maximum are from a southerly to south-westerly direction over land. It is interesting to note that the tracks from Halifax on Aug. 14 12Z suggest that the sulphate concentration maximum was not likely due to the low-level off-shore track but probably the result of the upper level tracks, in a well-mixed boundary layer, which traversed the high emissions areas south of the Great Lakes and across the East Coast states (9).

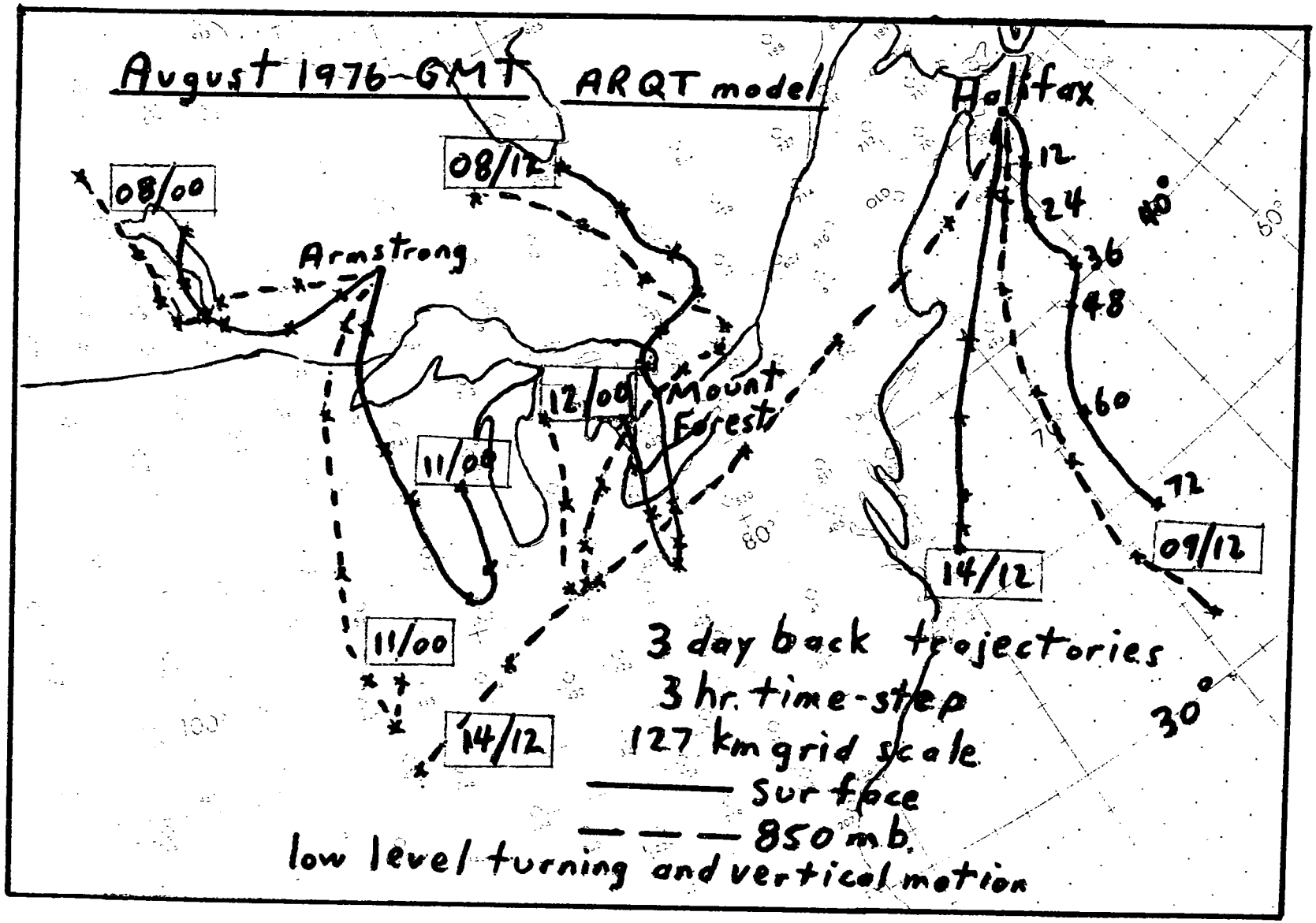

Figure 2. 3 day back trajectories at the surface and 850 mb from Halifax, Mount Forest and Armstrong for starting dates during August 1976.

SUMMARY

A flexible and reasonably complete trajectory modelling scheme has been formulated and implemented on a scale which is suitable to the problem of long-range transport of air pollutants. Large quantities of wind, temperature and height data must be retrieved, validated and organized before the trajectory model can be run. Trajectory comparisons tend to show acceptable inter-model comparability especially at levels above the surface. Multi-level operation of the model has shown that large trajectory divergences can occur as a result of vertical wind shear. By including the vertical motion capability, air parcels can rise and fall through the different wind regimes enroute to or from their origin points, thereby providing somewhat more realistic air parcel motions. The shearing effects have important implications when the trajectories are used to govern the motion of the boxes in the concentration/deposition box model (7).

A trajectory forecasting capability is being investigated whereby the forecast wind fields from the CMC spectral model are used to produce 48 hour forward trajectories at several levels from any site in North America. The forecast trajectories could be used to indicate air parcel motions from a particular site such as an industrial complex or in an emergency situation such as a nuclear reactor accident. The forecast trajectories could also be used with the concentration/deposition model to forecast the position and magnitude of potential air pollution episodes during field study activities.

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LONG-RANGE TRANSPORT: CONCENTRATION AND DEPOSITION MODELLING

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INTRODUCTION

Damage to the environment caused by nearby pollution sources is a long recognized problem. Much effort at this workshop has been devoted to analysing this problem through local and regional air pollution modelling, impact assessment and establishment of air quality criteria.

It is only recently, however, that one has become aware that pollutants released into the atmosphere may remain there for an extended period of time and travel thousands of kilometers before being removed. Thus, stringent local and regional control strategies may be inadequate to protect a specific area. This is evident in Scandinavia, where the acidification of the lakes is attributed to sulfur oxide emissions in Continental Europe and in the British Isles.

In Eastern Canada there is also mounting evidence of acidification of lakes. Certain lakes have already lost their buttering capacity, and an average pH in precipitation of 4.0 -4.2 has been measured in the Muskoka-Haliburton area.(CANSAP)

Acid rain is formed primarily by oxidation of oxides of sulfur and nitrogen with the release of hydrogen ions in the rain drops. It is presently assumed that around seventy percent of the acidity results from the oxidation of sulfur dioxide.

Preliminary studies (e.g. Whelpdale and Galloway, 1979; Voldner, Olson et al) indicate that to a large extent the Canadian acid rain problem originates from SO_2 emissions in the U.S.A. Other speakers have probably covered some aspects of this problem as well as discussed the possibility of an Air Treaty between U.S.A. and Canada.

The immediate objective of the LRTAP modelling program is to obtain an estimate of the trans-boundary sulphur fluxes

and concentration/deposition patterns of sulfur dioxide (SO_2) and sulfate over Eastern Canada on a seasonal and annual basis.

MODELS

Long-range transport models are by necessity rather simplistic. No model can presently handle detailed physical/chemical processes which start at the stack level and extend several days and thousands of kilometers beyond the point of emission. Most long-range transport models are applied several hours or tens of kilometers beyond the source. Generally models can be subdivided into episode models, which are Eulerian in approach allowing more emphasis on chemical processes and into Lagrangian models for longer time estimates. The intended use of our concentration/deposition model (Olson; Voldner et al) is to estimate the seasonal averages of SO_2 and particulate-sulfate concentration fields, wet and dry deposition, pH fields and border fluxes. It is a Lagrangian model based on a three-dimensional trajectory model. It has a modular structure that allows the model to be updated as required or as better information becomes available.

1. CONCENTRATION/DEPOSITION MODEL

An air parcel is assumed to follow a precomputed trajectory for 3-4 days across an annual emissions grid and to terminate at a given site. As the air parcel traverses the grid, SO_2 is released, instantaneously mixed, transformed to sulfate and both SO_2 and sulfate are removed by wet and dry deposition processes.

The basic equations which are integrated along the trajectories are:

$$\frac{dC_1}{dt} = -\left(k + \frac{Vd_1 + Vw_1}{H}\right) C_1 + f_1 \frac{Q_1}{H} \qquad (1)$$

$$\frac{dC_2}{dt} = 3/2\left(kC_1\right) - \left(\frac{Vd_2 + Vw_2}{H}\right) C_2 + f_2 \frac{Q_2}{H} \qquad (2)$$

where

C_1 = concentration of SO_2
C_2 = concentration of sulfate
$Q_{1,2}$ = emission flux of SO_2 and sulfate, respectively
k = rate constant for conversion of SO_2 to sulfate
Vd = dry deposition velocity
Vw = wet deposition velocity
H = mixing height
f = factor accounting for local transformation and deposition.

It is assumed that the pollutants are mixed instantaneously throughout the mixing layer and that there is no transport through the top of the layer (inversion). The assumptions are reasonable for mesoscale and synoptic scale modelling at low level sources but are not adequate for modelling tall stacks, which may emit above the mixed layer. However, the present inventory does not differentiate between low and high level sources. In the model, the mixing height can either be assumed to be a constant or to vary diurnally and seasonally according to mixing height climatologies from Holzworth and Portelli. (Portelli, 1977)

The horizontal dispersion of a pollutant, except in the immediate vicinity of a source, is due primarily to vertical wind shear and turbulence. This effect is accounted for indirectly by the lack of resolution in the emissions inventory, where the emissions are assumed to be evenly distributed on a 127 X 127km grid. Further, since the vertical wind shear can be substantial, the concentration at a station can be computed either from isobaric trajectories or from trajectories which incorporate vertical motion and terminate at selected levels. (eg. 1000, 925, 850 mb).

The concentration at a station is normally computed as an average of concentrations obtained from integrations along three trajectories arriving at different levels.

The formation of sulfate from SO_2 is extremely complex. However, for long-range transport modelling, it is generally

accepted that after the first few hours following release, the oxidation rate falls in the range of 0.7 - 1.5 percent per hour. Thus a first order reaction has been assumed here.

Dry deposition is parameterized by a deposition velocity, Vd. Values of the deposition velocities for SO_2 and sulfate have been found to vary with surface type, time of day and meteorological conditions (see a selection of papers in Atmospheric Environment, 1978). The measured values normally fall within the range 0.1 - 2.0 cm/s and 0.02 - 0.6 cm/s, respectively. Sensitivity studies performed with other LRTAP models (Shannon) indicate that incorporation of a diurnal variation in the deposition velocity has little influence on seasonal estimates. Thus Vd has been kept constant.

The surface dry deposition fluxes in SO_2 and sulfate are equal to Vd X C.

Wet deposition is also an important removal mechanism for pollutants. It depends on chemical composition and physical characteristics of the pollutants, the presence of other pollutants, meteorological conditions such as duration, intensity and frequency of precipitation events and the relative effectiveness of in-cloud or below-cloud processes (Slinn). Because such detailed information is rarely available, and precipitation fields with high spatial and temporal resolutions are difficult to obtain, a simple approach suggested by Slinn has been used here.

A wet deposition velocity is defined as follows:

$$Vw = \alpha P$$

where α is the volumetric wash-out coefficient and P is the precipitation rate.

The actual "decay rate" for the pollutants becomes $k_w = \alpha P/H$. "Representative" values of α for SO_2 and sulfate are in the order of 10^4 and 10^5, respectively.

Precipitation pH is computed by assuming sulfate in precipitation is in the form of sulfuric acid. This is normally not the case, but since pH is the negative logarithm of the hydrogen ion concentration, it is not too sensitive to the

assumption.

One resulting formula is:

$$pH = -\log (\alpha . C * 2.08 \cdot 10^{-11} + 10^{-5.6})$$

where C is the concentration of sulfate in the air in $\mu g/m^3$.

Border fluxes are computed from the relation:

$$\Sigma_1^N C \overline{V}_N \cdot H \cdot L$$

where $\overline{V}_N$ is the wind component normal to the boundary, L the length of a boundary segment, N the number of segments, C is the concentration at the border point and H is the mixing height.

2. INPUT

The wind fields used to compute the trajectories and the structure of the trajectory model have been described in the paper entitled "Trajectory Models".

The precipitation fields are obtained from an objective analysis at the Canadian Meteorological Center (CMC). The precipitation is given as twenty-four hour totals on the CMC 127 km grid and is assumed to be evenly distributed throughout the twenty-four hour period.

The spatial distribution of the source term Q is obtained from a North American inventory (Voldner and Shah, 1979). The inventory gives annual emission rates for SO_2 in kilotonnes /year on the CMC 127 km grid. The inventory does not contain information on stack parameters. The data for the U.S.A. are mainly from 1969-70, while the Canadian data are from 1974.

3. COMPARISON BETWEEN MEASURED AND COMPUTED QUANTITIES

In order to assess the model performance, it is important to compare results obtained from the model with actual experimental data. Data from different networks across eastern North America are being assembled for this purpose. Several problems arise when one attempts to compare computed and measured quantities. Only a few will be listed here.

(1) Lack of uniformity in measurements. In Canada we

have essentially only values for wet deposition. In U.S.A. the emphasis is on pollutant concentrations in the atmosphere.

(2) The different networks use different types of instruments, operate at different time intervals and resolutions. This may lead to difference in results for the same measured parameters. Several gaps in network data due to equipment failure usually occur.

(3) Representativeness of data.

- errors in measurements
- the monitor may reflect local effect rather than regional
- ground based monitors.

(4) Preliminary Results

The Model has been compared with data from the Intensive Sulfate Study in Canada, August 1976 (Voldner, Olson et al). It is presently being evaluated over Eastern North America using data for October 1977. The preliminary results are as follows:

- The model is capable of duplicating the occurrence of air pollution episodes in space and time, although the computed values are occasionally twice the measured ones.
- Measured and computed SO_2 and sulfate concentrations in the atmosphere, averaged over a month, show the same spatial distribution, although the magnitude can differ by a factor of two.
- The ratio of computed to measured sulfate concentrations in precipitation averaged over a month is higher in U.S.A. than in Canada. This trend can be expected because of the difference in sampling method used in the two countries. (Whelpdale,1979).
- Measured and computed monthly precipitation pH values are within a few per cent of each other.

The difference between computed and measured values can be explained from uncertainties in the parameterization, uncer-

tainties in the measurements and lack of suitable precipitation data. Further, the inventory is too high and has a coarse temporal and spatial resolution.

Sensitivity and evaluation studies are continuing to identify the processes and input quantities, which require improved parameterization and resolutions.

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DISCUSSION/COMMENTS

J.W.S. YOUNG: Is this trajectory model available on a utility basis to outside users yet?

M. OLSON: No, it is not Jim.

J.W.S. YOUNG: Will it become available?

M. OLSON: That depends on whether we have the manpower and the resources to split it off from this particular application into sort of a stand-alone module, wherein people can ask for what they would like, and someone there is able to bring the data together and do it. At the moment that capability does not exist, but we are looking to doing that as time and resources permit.

J.W.S. YOUNG: Can you give me an estimate of approximately what time and resources would be required to produce it into that type of version?

M. OLSON: At least probably six months, with one person to help us out to do that.

J.D. REID: I think this is a very exciting application particularly the concentrations that you predicted, and I'm really pleased to see things getting to this stage. It's very good. One small point of clarification in the sulphate study. What level was the trajectory that you used? Was it the average of a number of trajectories?

M. OLSON: We used three levels of trajectories; the surface, 925 and 850 millibars. Each track had a box associated with it, so that each day there was rolled up actually 12 concentrations; at three levels, four times a day.

J.D. REID: For the trajectories aloft, it was assumed that the surface emission sort of mixed instantaneously into the top?

M. OLSON: Yes.

B. WEISMAN: That one example you showed where you had a maximum of sulphate at Chalk River, how long was that trajectory getting up to Chalk River from the Eastern States?

M. OLSON: I'm not sure, I think it was 3 or 4 days.

B. WEISMAN: Given the fact that your maximum sulphate in the air might peak at one day or maybe at the most two days, how is it that you get one peak up at Chalk River, nothing high leading up to it? How do you get an isolated point concentration of sulphate at that kind of time travel from the source?

M. OLSON: That diagram was sort of one snapshot in time. We had a certain time period. If you'd looked at the time period, say, maybe six hours before, you probably would have seen also a maximum somewhere, perhaps also at Chalk River.

B. WEISMAN: Are you saying those emissions are intermittent in your model from the boxes?

M. OLSON: That's only the end of the track. If you look at a site maybe 60 miles south of Chalk River and looked at that, you'd probably also have seen some kind of maximum there, if the trajectory had of been somewhat similar.

B. WEISMAN: Oh, I thought you had mapped out the concentration contours. You were just looking at several points, is that right?

M. OLSON: Only the points for which I had values, and then I had contoured it as best I could, so I don't really know what was in between some of those points. It could be that that maximum was long or elongated or some different shape but I really don't know.

REGIONAL AND GLOBAL AIR POLLUTION

D.M. WHELPDALE
Atmospheric Dispersion Division

INTRODUCTION

In the past air pollution was usually associated with a relatively small geographical area and a rather easily identified able source of pollutants. Even today, when we are confronted in our professional capacity with an air pollution problem, nine times out of ten it will be associated with the perceived or potential effects in the neighborhood of a particular smelter, fossil-fuel-fired generating station, city, etc. We are rarely asked to explain or solve an air pollution problem on the larger scale.

But more and more awareness is growing that air pollutants which travel away from their sources of emission can pose serious problems on the regional to global scales. It is useful to examine the question of scale (Table 1). (As one can imagine a regional-scale pollution problem in eastern North America is a different beast than a regional-scale pollution problem in Holland.) Pollution situations can be grouped conveniently, if somewhat arbitrarily, into four distance scales: local, regional, continental and global. If a distance of the order of 10 km is characteristic of the local situation, then an increase by an order of magnitude for each subsequent scale is appropriate.

An obvious requirement for the larger-scale pollution problem is that the substance or substances in question have an atmospheric lifetime sufficiently long to be transported over large distances. For example, in the absence of intense photochemical activity SO_2 has a lifetime of a few days, and this is important from a regional transport point of view. Sulfate particles in the stratosphere, fluorocarbons and carbon dioxide have much longer lifetimes (the order of years) and thus are important globally.

Table 1. Scale of Pollution Problems

GLOBAL	10,000		carbon dioxide increase
			stratospheric ozone depletion
CONTINENTAL	1,000		dust transport and Arctic haze
			transport of pollutants to the oceans
			increasing turbidity
		km	airborne sulfate
			long-range transport/acid precipitation
REGIONAL	100		photochemical oxidant transport
LOCAL	10		urban pollution
			automobile CO
			municipal incinerator
			neighbour's fireplace or chicken farm

LARGER-SCALE POLLUTION PROBLEMS

The list of regional, continental and global scale pollution problems is long (Table 1). Below we look briefly at three: the regional sulfur and acidic rain problem, dust transport and Arctic haze, and global CO_2.

REGIONAL-SCALE SULFUR AND ACIDIC PRECIPITATION

Perhaps the most serious environmental problem facing us today in eastern North America, and particularly in eastern Canada, is associated with the increasing emissions of sulfur and nitrogen oxides on this continent. Much of eastern North America is frequently affected by episodes of regional-scale pollution, in the form of both airborne suspended particulates and acidic precipitation. Non-urban sulfate levels are documented to be increasing and atmospheric visibility, which is well correlated with atmospheric particulate sulfate concentration, is decreasing. Over the past few decades the pH (acidity) of precipitation has been decreasing (increasing) and the corresponding deposition of acidic components increasing. The adverse effects of the latter on our aquatic ecosystems are of immediate and serious concern. A recent Ontario report stated that 140 Ontario lakes are now irreparably damaged and that another 48,000 will suffer a similar fate in the coming decade or two. Both these effects and the DOE program mounted to investigate the long-range transport/acidic precipitation phenomena will be discussed in a later presentation.

DUST TRANSPORT AND ARCTIC HAZE

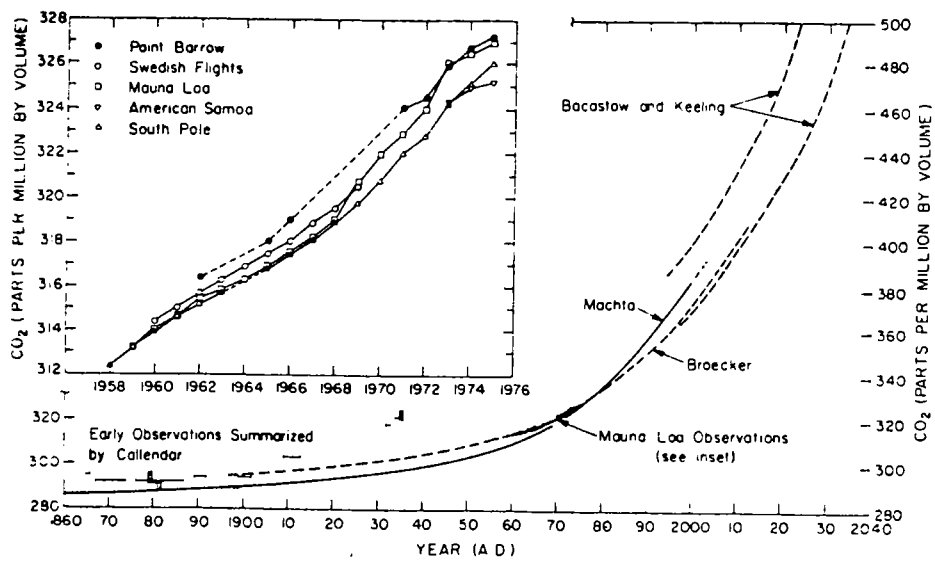
For several years relatively high loadings of dust have been measured at the Barbados. This material originates in the Sahara Desert during dust storms and is transported across the Atlantic, some eight thousand km. Until recently this phenomenon was accepted more as a curiosity, an indication of the potential for atmospheric transport of airborne material, rather than as

a pollution problem. But recently, Rahn and associates at the University of Rhode Island and the University of Alaska have been investigating the occurrence of layers of haze in the Arctic, particularly during winter, and have come to the conclusion that both natural material from the world's great deserts (in China and Africa), and from man's activity (e.g. fossil fuel combustion) are contributing to the observed Arctic haze. The environmental concerns associated with this phenomenon are twofold: first, a visible deterioration of air quality (reduced visibility) and second, interference in the radiation balance of the Arctic. This example serves to demonstrate the possible completely unsuspected impacts that may result from the combination of pollutant emissions and large-scale meteorological transport.

THE GLOBAL CO_2 PROBLEM

Since the Industrial Revolution coal, petroleum and natural gas have been burned for heat and power production with the resulting release of CO_2 (Figure 1). Approximately half of all the CO_2 so released is still in the atmosphere and the other half has been dissolved in the oceans or gone into the Earth's biomass. The major concern with increasing CO_2 levels is the effect on the heat balance, since CO_2 is virtually transparent to solar radiation but absorbs outgoing terrestrial infra-red radiation. The result is an increase in surface temperature, accompanied by a corresponding decrease in stratospheric temperature. (This is referred to as the "greenhouse effect".) A recent review of model calculations to show the influence of CO_2 on surface temperature estimates that the 25% increase in CO_2 expected by the year 2000 will cause a mean surface temperature increase of 0.5 to 2 C. Changes in polar regions would be expected to be three to five times greater than this average. Such changes may be accompanied by substantial alterations of the patterns of rainfall, global atmospheric circulation, and polar ice extent. The CO_2 problem is one of the two most

Figure 1. Carbon Dioxide (Kellogg, 1977 p 234, 235)



The record of carbon-dioxide concentration from 1860 to 1975, measured at several locations, and some estimates of future trends. The early data were critically reviewed by Callendar (1958) and subsequently re-evaluated by Barrett (1975). The current series of observations for Mauna Loa are those reported by Keeling *et al.* (1976a) and C. D. Keeling (personal communication), for South Pole by Keeling *et al.* (1976b) and Keeling (personal communication), for American Samoa and Point Barrow by NOAA (1975) and T. Harris (personal communication), and for the Swedish aircraft observations by Bolin and Bischof (1970). Note that the carbon-dioxide concentrations are given in terms of the 'adjusted index values' (for the sake of continuity with the earlier data); it may be necessary to adjust these values upward by about 3 to 4 ppmv, according to Keeling *et al.* (1976a), to obtain the correct mole-fraction, but this would not affect the slopes of the curves. The model calculations predicting future carbon-dioxide increases by Machta (1973), Broecker (1975), and Bacastow and Keeling (1973) all take account of the take-up of anthropogenic carbon dioxide by oceans and the biomass (but in somewhat different ways), and assume a quasi-exponential increase in the rate of burning of fossil fuels (notably coal) in the next half-century or more. It is expected that in this time period about half of the new carbon dioxide released will remain in the atmosphere; and due to the slow mixing of deep ocean waters with the upper layers, the decay time of the added carbon dioxide, were we to stop producing it, is estimated to be 1000 to 1500 years

TABLE

Effects of adding carbon dioxide to the atmosphere

Factor of change of carbon dioxide from present per cent	*Expected time for change to occur*	*Mean surface temperature increase* deg C
+25	2000 AD	0.5 to 2
+100	2050 AD	1.5 to 6

important large-scale pollution problems recognized in the United States by the President's Council on Environmental Quality. (The other is acidic precipitation).

THE WMO NETWORK FOR MONITORING BACKGROUND AIR POLLUTION

The function of the WMO Background Air Pollution Monitoring Network is to obtain measurements on a global and regional basis, of background concentrations of atmospheric constituents. From the variability in time and space and the possible long-term changes of these data it will be possible to assess the influence of human and natural occurrences on the composition of the atmosphere. Such information is required:

(a) to study the effects of atmospheric composition on climate, and the prediction of future climate change due to future activities of man;

(b) to aid in the study of the mechanisms of long-range atmospheric transport and deposition of potentially harmful substances;

(c) to aid the study of the biogeochemical cycles of important constituents in order to establish a sound basis for assessing human impact of these cycles and for making predictions of possible impacts on the environment.

WMO has identified three types of station: baseline, regional and regional with extended programme:

Baseline stations

The nature of the baseline monitoring programme implies a strong research component. Its function is mainly to obtain background concentration constituents with long residence times in the atmosphere and which are important to climate or a general indication of human activity.

Regional stations

The primary purpose of these stations is to document long-term changes in atmospheric composition which may be related to changes in regional land-use practices or other man-induced activities.

Regional stations with extended programmes

The functions of these stations is to monitor atmospheric compounds which are not part of the minimum programme for regional stations but which are of interest as indicators of a surface exchange on scales larger than regional.

Table 2 shows a number of features of the various types of stations.

Table 2. WMO Network for Monitoring Background Air Pollution

STATION TYPE	SCALE OF PHENOMENA SPACE (km)	TIME (y)	VARIABLES MEASURED *	OBJECTIVES	NUMBER
Baseline	10^4	>1	CO_2*, chemical comp. of precip.*, solar radiation* (including turbidity), N_2O, CO, CH_3, total and surface O_3, condensation nuclei.	I. Determine global inventories and their trends. II. Determine latitudinal transport for global biogeophysical modelling	∿ 5 5 - 10
Regional with Extended Program	10^3	0.01 -0.1	CO_2*, chemical comp. of precip.*, solar radiation* (including turbidity), N_2O, CO, CH_3, total and surface O_3, condensation nuclei, gaseous sulfur and nitrogen compounds*, suspended particulate matter*, chemical composition of particulates*.	III. Determine air-surface exchange within, and atmospheric transport between large-scale areas characterized by different biomes and different sea surface conditions.	10 - 20
Regional	10^2-10^3	hours days	Gaseous sulfur and nitrogen compounds, suspended particulate matter*, chemical composition of precipitation and of particulates*, turbidity*, surface O_3.	IV. Determine air-surface exchange and atmospheric transport and possible long-term trends within regions characterized by significant man-made influences and possible long-term changes in atmospheric composition.	>100

* Priority Measurements

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DISCUSSION/COMMENTS

R.M. HOFF: You began by showing decreases in visibility when you were discussing the sulphate problem. Is that a foregone conclusion now, that the decrease in visibility is due to sulphates?

D.M. WHELPDALE: Yes, there is a very good correlation now between atmospheric sulphate load and the visibility. The mass of sulphate is about 20% of the total load. It's very well correlated. In fact, one of the reasons for establishing the sulphate standards in the United States is on the basis of the visibility as opposed to health hazard.

R.V. PORTELLI: What type of meteorological studies would you recommend in conjunction with these measurement programs to maybe augment them and incorporate let's say synoptic situations which effect the loadings, etc?

D.M. WHELPDALE: Well, I think there are two aspects to that. You said over the long term. I think that one of the important things with the event type study is to identify exactly where the pollution is coming from, it it's transported over long distances. I guess that's the other end of the scale. For the longer term, we've been working on one base year of data so far and getting meteorological statistics on the year of data. Obviously that's not that much. We'll have to got to several years to make sure we get representativeness. I suppose we can compile statistics of trajectory endpoints and examine deposition and concentration fields under different meteorological conditions.

K. PETTIT: Doug, the present CO_2 concentration average-wise is about 325 parts per million. You were quoting cases for 25% increase. This is an increase of say 75 - 100 parts per million by the year 2000. The rate of increase up until about 1970 was .7 parts per million, and since then has run up to a little over 1.1 part per million, but what you're suggesting is that we're going to have an average increase in the next less that 25 years of more than four parts per million. This is from your models. Do you think this is actually a reasonable estimate? This means that our 1 part per million, let's

say it continues for the next 5 years or so, means you're going to have to have 10 parts per million in the last 10 years of the century. When you consider what's happening to our resources and the way we're using them, and how we're being forced to cut down, it seems to me that people may be being a little pessimistic.

D.M. WHELPDALE: I think you know more about the details of this than I do, Ken. I would suggest that there's not a lot of evidence at the moment that fuel combustion has been cut back significantly in the industrialized parts of the world. I know we like to see that but I don't think there's a lot of evidence to that fact yet. These estimates of 25% increase by the year 2000 are based on a number of model calculations and it looks like an exponential increase not a steady increase.

K. PETTIT: This is a case where we can agree to disagree. The increase in fuel consumption, it being one of the causes of CO_2 increase, possibly, I'm just saying, to me there's a good chance that it will not increase exponentially with the restrictions that are being put on us at the present time.

STRATOSPHERIC POLLUTION AND CLIMATE CHANGE

W.F.J. EVANS
Experimental Studies Division

INTRODUCTION

In the Experimental Studies Division, research is conducted in three major areas: stratospheric pollution, ozone monitoring and solar radiation. We will consider these in order, beginning with stratospheric pollution problems. It is difficult to put a priority on these problems, but personally, I think the stratospheric pollution problem may be as serious as the CO_2 problem. Figure 1 shows the ozone layer which screens out the ultra violet rays of the sun, as well as various source compounds which originate from the surface of the earth, and diffuse up into the ozone layer and hence control the ozone balance. In particular, N_2O is produced from the oceans and the land masses and methyl chloride comes out of the sea. These are the natural sources of nitrogen and chlorine compounds in the stratosphere. Lately man has come up with ways to augment these natural sources with supersonic aircraft (jet engine emissions) and the use of CFM's (chlorofluoromethanes). In general, CFM usage is not limited just to aerosol spray cans, but also comes from refrigeration, air conditioning and plastics manufacturing. To give you some details of the freon ozone problem, we are releasing freons (F11 - $CFCl_3$, F12 - CF_2Cl_2) into the troposphere; these get mixed and transported upwards through the tropopause into the stratosphere. Once they are into the stratosphere above the ozone layer, they can be broken up by ultraviolet sunlight to give atomic chlorine, which then reacts with ozone to give ClO, and this can be cycled back to Cl by reaction with atomic oxygen. This forms a catalytic cycle which converts odd oxygen (ozone and atomic oxygen) back into molecular oxygen. Now there is a sink for chlorine in the stratosphere which consists of the reaction of methane and atomic chlorine to give hydrochloric acid. Hydrochloric acid is then transported downwards into the

troposphere, and as soon as it gets into clouds, it is "rained out" to the surface. There are pollution sources of hydrochloric acid in the troposphere as well, and some component of the acid rain may be due to hydrochloric acid. Now, contrary to the CO_2 problem, we already have the required production level of freons to give us a very serious problem. Figure 3 shows the world production of freons from 1958 to 1979 for freon 12, ~1,000 million tons per year and for freon 11, ~600 million tons per year. Of this problem, Canada contributes 2 or 3%. Now, with those production rates (usage and production rates of freons are approximately constant currently), and we expect them to stay constant for the next 10, 20 or 50 years unless we make a deliberate attempt to reduce them, we have arrived at the current concentrations in the atmosphere (Figure 4) of freon 11 of 125 parts per trillion, and freon 12 of 220 parts per trillion. These atmospheric concentrations are increasing at the rate of something like 10% per year, and they will go on increasing until the year 2100 at the current production rates. At that time both freons will have concentrations of 2 or 3 ppbv. CCl_4 is present in the atmosphere at 120 pptv. Again, it is probably mostly anthropogenic in origin. There has been some speculation as to the size of the contribution of the natural source, but it's probably not more than one-third of the total. The other chlorocarbon present in the troposphere is methyl chloride, the natural source of chlorine in the atmosphere that exists at something like 600 parts per trillion, although there may be a manmade component to that as well. The other interesting one is called methylchloroform (MCF), which is now present at 120 pptv. The production rate of MCF is currently the same as freon 11, but it is increasing at more like 20% per year rather than 10%.

In regard to verification that the freons are actually getting into the stratosphere, a summary of measurements by various groups is shown in Figure 5. There is a fall off with

altitude; we have the order of .1 ppbv in the troposphere, and then up at the tropopause one starts to see a sharp fall off which shows that freons are (1) actually getting up into the stratosphere and (2) actually being broken up by uv sunlight. Now, what we must consider is the time scenario for freons this is shown in Figure 6, a plot of ozone depletion as a function of the year (~8% by the year 2005, ~6% by 1995, ~4% by 1985). By 1985 we'll be looking at something in excess of a 3 1/2% ozone depletion at our current freon usage rates. Now, we should consider what we could possibly do to avoid a serious depletion: one strategy would be to cut the use of freons to 1/3 of the current rate which is shown by the curve in Figure 6b. If, in 1985, we cut the usage to 1/3 (which is a most realistic scenario of what we could do, in a regulation sense), this would result in a long-term ozone depletion of 7 or 8%, and would still give us a 5% ozone depletion by 1995. The other thing we could do is to stop using freons completely in 1985, although this may not be a feasible situation in terms of an industrial shift, and even if we did that, we would still arrive at something like a 4 1/2% ozone depletion in 1995 followed by a very long, slow recovery with a time constant of about 50 years as shown in Figure 6c.

The essential message behind the freon problem is, that if our current understanding of the science is correct, then we have already created a problem for ourselves which is going to have severe environmental effects, and that we are going to have to live with for many years. The only thing we can do is make this problem less severe. Now that's only the problem due to freon 11 and freon 12. The methylchloroform problem is somewhat similar and is demonstrated in Figure 7. If we go on using methylchloroform at our current rates, we are going to produce a 2% ozone depletion in 1985 from MCF alone, and that will be piled on top of the freon 11

and freon 12 depletions. The upper curve shows what happens if we keep on using methylchloroform at a continually increasing rate as is currently indicated. Again, this is probably not a valid scenario. If we leveled out the usage rate to the 1985 rate, we would arrive at the curve which gives a steady rate depletion of something like 3 1/2% to 4%. So, obviously methylchloroform poses a serious problem as well, and it may be a problem that we should act on now before we do something about freons. Freons have another effect; they produce a greenhouse effect very analagous to the CO_2 greenhouse effect, and for the 1973 buildup scenario one would get, at least, with the same certainty as one would get a CO_2 warming globally, an increase of 1 to 1 1/2% in the global temperature; the same model that produced these estimations gives an increase for doubling CO_2 of 2 1/2 to 3°K. It is interesting to note, if one does an extrapolation using the current mixing ratios of freons in the atmosphere, that we already may have had something like a 1/10 of a degree K warming in the global temperature from using freons. A little bit of freon goes a long way, when it comes to greenhouse effects. Aside from effects on the ozone layer, freons are not highly attractive from the greenhouse effect point of view either. We should consider limiting usage even for this reason.

STRATOSPHERIC POLLUTION

What has our research division been doing about these problems? We have been making balloon flights into the stratosphere with instrumentation to measure some of these gases and to understand the chemistry. We are trying to define this problem both qualitatively, to find out if the basic elements of the freon ozone hypotheses are correct, and quantitively to find out some of the error limits on the model projections. For example, we don't really know, although we have a long-term projection of a 15% ozone depletion, whether it might be as small as 5% or as large as 30%.

On the balloon flights that we have been making, we initially started out studying the nitrogen chemistry of the stratosphere; in 1977 we began making measurements of the chlorine chemistry, in particular HCl and freons, and lately we have been making intercomparison studies with the Nimbus 7 satellite. Our balloon measurements provide a different view of the freon ozone problem than the currently accepted scientific status; our measurements indicate that the hydroxyl concentrations in the stratosphere are considerably smaller than currently modelled. Figure 8 shows the projections of ozone depletion using the modifications of the chemistry that would be implied by our balloon measurements. For example, they indicate that instead of a 17 1/2% ozone reduction, we might expect something as small as a 5% ozone reduction, at the current usage rate of CFM's. These measurements also have implications for the injections of NO_x from jet aircraft, and they indicate instead of small effects from NO_x injections, ozone depletions ranging from 5 to 10% as were current at the end of CIAP in 1975. In a scenario sense, the upper curve is a repeat of the standard calculation of freon ozone depletion, and the lower curve is the depletion with time that would be implied by our balloon measurements; if our measurements are correct, then the problem is not nearly as severe as currently projected. For example, in 1985 we would expect only something like a 1% ozone depletion, even though there would still be a long term problem. Most biologists think that a 5% reduction in the ozone layer is unacceptable and we should maintain it below that.

OZONE MONITORING

The second part of our activities is ozone monitoring, and fits in well with the complimentary measurements of stratospheric pollution, because the other end of this problem is to actually try to measure a decrease in the ozone layer. Figure 9 is a listing of the activities we are involved in on ozone

monitoring. We operate the Canadian Ozone Network, which has stations at Churchill, Edmonton, Goose Bay and Resolute. Dobson measurements, intercalibration and testing are conducted at Toronto. In addition to the total ozone measurements, there are also ozonesonde flights once a week from each of the four stations to monitor the shape of the ozone profile. We also publish the World Ozone Data. We calibrate and maintain the Canadian network by measurements and calibration procedures here at Toronto. We participate in international comparisons of Dobson and ozonesondes. Currently, we are refurbishing some of the Dobsons in the world for the WMO, in particular, the Belgium and Chinese Dobsons. Currently we are developing a new instrument to replace the Dobsons in the ozone network; the Dobson is rather an outdated instrument, and we are developing a new digital instrument. As well, we are beginning to make ground based measurements of NO_2 with the long-term objective of trying to combine those with the ozone measurements. Recently, we have discovered a problem, in that the Dobson ozone instruments seem to be sensitive to SO_2; we plan to evaluate background SO_2 by measurements of the total amount of SO_2 between the ground and the sun which would also have applications for air pollution studies. In order to show how ozone is distributed around the world, and in particular, over Canada, a picture of the annually averaged ozone distribution is shown in Figure 10; there are about 220 Dobson units of ozone around the equator, and ozone increases up to 400 units at 70° North. In Canada most of the year there are from 300 to 360 Dobson units of ozone. Ozone shields out the biologically active ultra-violet action portion of the solar spectrum; Figure 11 shows the increase in erythemal radiation as a function of the decrease in total ozone. For example, for a decrease in ozone of 10% we get something like a 21% increase in erythemal radiation. Now, if we extend the previous graph of ozone distribution into a UVB radiation calculation, we can

obtain the erythemal radiation as a function of latitude and of season; in Canada, we should consider latitudes between 40 and 60° where we have a large maximum in June, July and August. What happens if we get a 10% decrease in the ozone layer? This is shown in Figure 13 for a springtime condition. The increase in the solar radiance at 297.5 nm is shown as a function of latitude; this is a calculation for the present ozone distribution (a typical one) and shows what happens if we have a 10% ozone depletion. At the equator you get something like a 20% increase in the UV where as at 50° we get more like a 30% increase, and where the ozone layer is thick one could get a 50 to 60% increase in UV. That's probably not terribly interesting because we don't receive much UV radiation in winter anyway, and we should be concerned with the summer situation; for a 10% decrease in ozone here, we appear to get a 20 to 25% increase in UVB. The situation, however, is more complicated than that because the models project that the ozone depletion in higher latitudes will be greater. So putting this all together, one would estimate that if we do get an ozone depletion of 10% globally, that might mean a 15% depletion at 50° and considering this factor, say a 25% increase in UVB, then perhaps we could get a 30 or 40% increase in UVB at Canadian latitudes if we had a 10% global ozone depletion. One should also note that the skin cancer incidence rate goes up as a factor 2 with the UVB increase, so that could mean on the order of a 50 or 60% increase in skin cancer rates in Canadian latitudes. For the Canadian scene perhaps, we should be less concerned about the skin cancer rates than the effects of a change in the UV environment on our cereal crop production; these effects should be evaluated since they are not necessarily negligible. Some of the data from the Canadian ozone monitoring stations from 1958 through to 1979 is shown in Figure 14. The variation shown by the top curve illustrates the biennial oscillation

while in the bottom curve the biennial oscillation has been taken out to give a curve suitable for looking for trends; the major feature we can see is an increase or a solar cycle variation from 1960 up to 1970. We cannot see any obvious indication of a decrease in the ozone layer. Our accuracy on this should be something on the order of 2%, but this does not mean that in the next few years we won't see the record go down rapidly. We have a good ozone network in Canada, and it is probably capable of detecting something like a 3 or 4% decrease in the ozone layer by 1985.

SOLAR RADIATION

The last Figure describes briefly our work in solar radiation. In the Experimental Studies Division we maintain the calibration and instrumentation for the solar radiation measurement network across Canada. The applications of these measurements are in deriving a solar energy data base by combining them with a current program in special measurements. The data itself is useful for climate studies and it could also tell us something about the long term effects of air pollution. For example, Mateer and Latimer have looked at the Toronto solar radiation data and they were able to see an improvement in the atmospheric transmission in the 50's and 60's which they attributed to the change-over from coal burning in locomotives; the data can be used for studying how the atmospheric transmission or turbidity at particular stations may have changed over time. As well we are currently planning on the acquisition of an instrument for making UVB measurements, (measurements in the ultra-violet portion of the solar spectrum), and we will then compare the results of the UVB measurements with the ozone measurements. We do not currently have a UVB climatology for Canada, and it would be difficult to answer any questions about skin cancer potential or agricultural applications; we intend to do some work in this area to develop a data base. This concludes the summary of the activites of the Experimental Studies Division.

DISCUSSION/COMMENTS

R. GILBERT: We are talking about the ozone depletion in the stratosphere and the consequence of this on (skin) cancer, but what about the ozone in the boundary layer which is apparently increasing as a lower filter for (solar) radiation?

W.J.F. EVANS: Due to air pollution activities, particularly production of NO_x and some direct production of ozone, there has been a few percent increase of ozone in the boundary layer. I think that's beneficial because it will tend to cancel out any decreases in the stratospheric ozone shield. I should also point out that SO_2 is a very good chemical in this sense since it has an absorption spectrum similar to ozone so increasing the SO_2 also protects us somewhat from increased UV-B levels.

STRATOSPHERIC POLLUTION

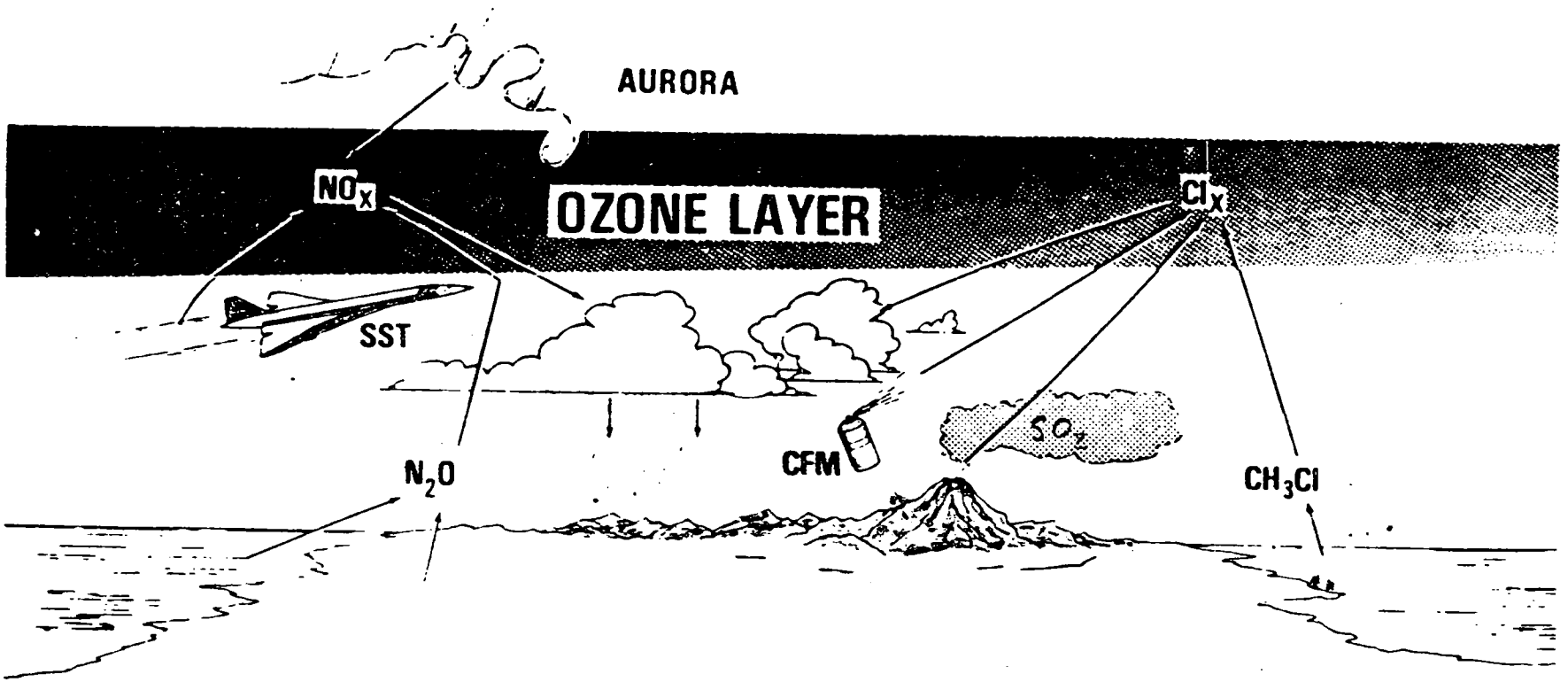


Figure 1

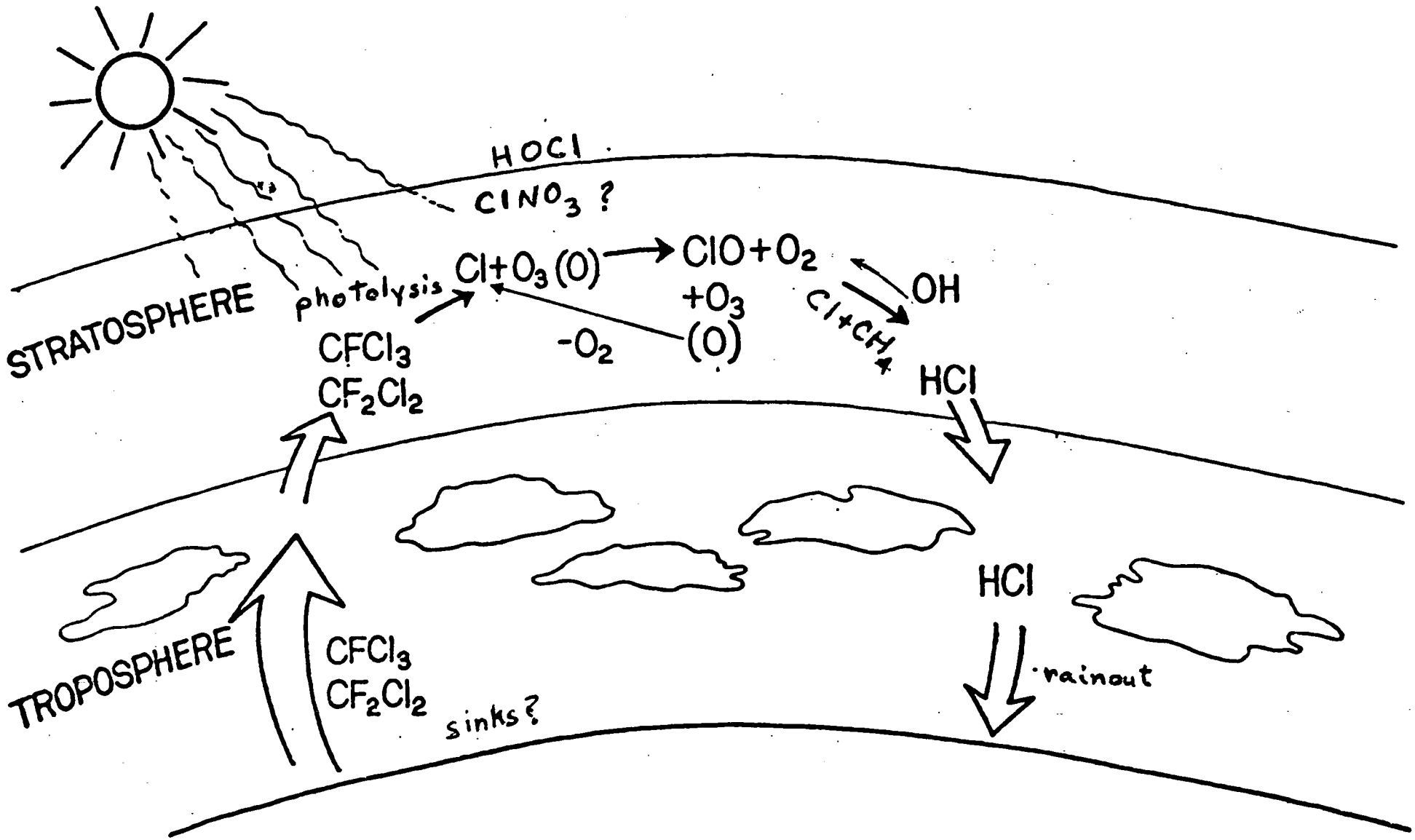

HOCl
ClNO3 ?
STRATOSPHERE
photolysis
Cl+O3 (O)
ClO+O2
+O3
(O)
-O2
Cl+CH4
OH
HCl
CFCl3
CF2Cl2
TROPOSPHERE
CFCl3
CF2Cl2
sinks?
HCl
rainout

Figure 2

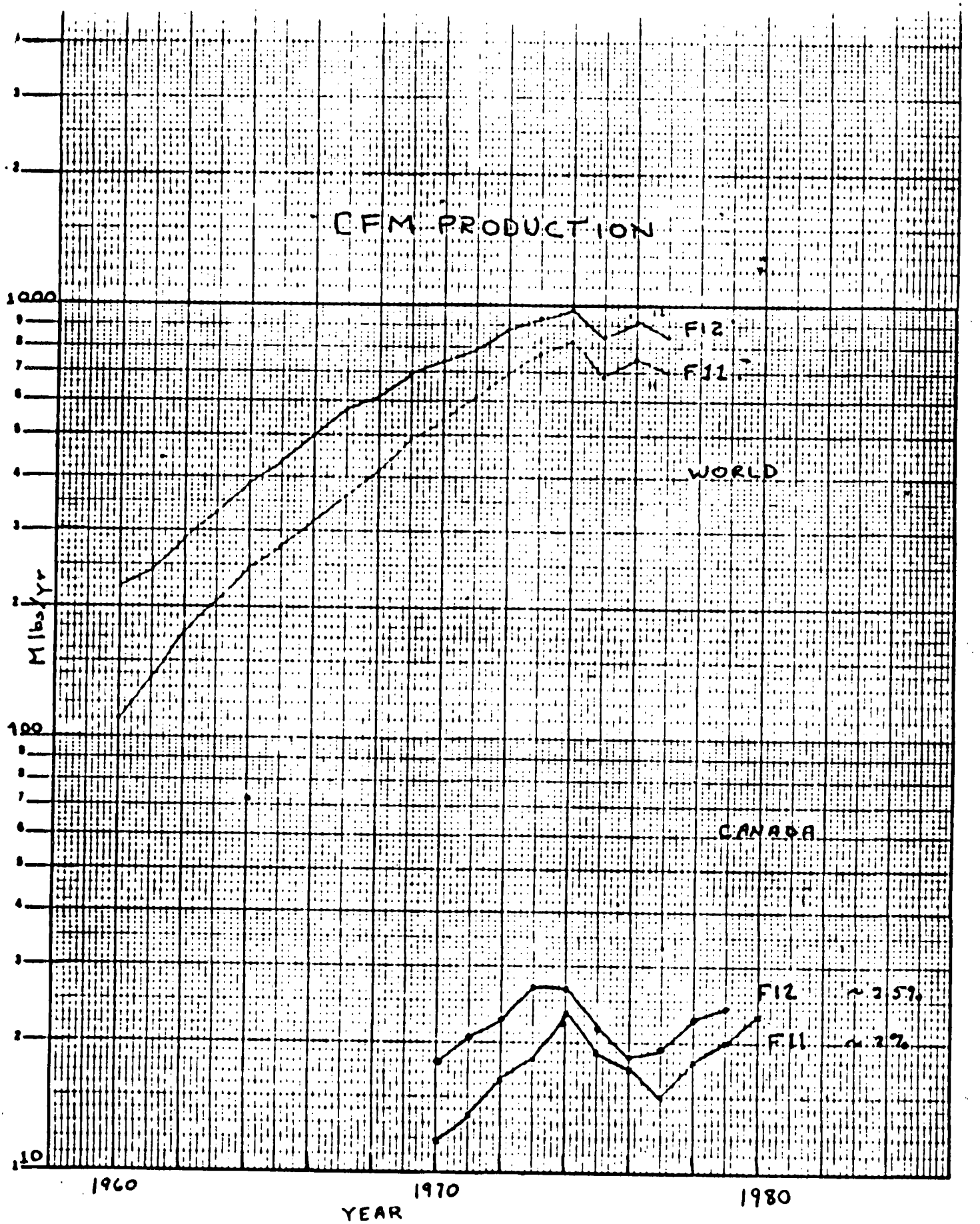

CFM PRODUCTION
F12
F11
WORLD
CANADA
F12 ~25%
F11 ~2%
M lbs/yr
1000
100
10
1960
1970
1980
YEAR

Figure 3

Chlorocarbons in the Atmosphere

	CH_3Cl	CCl_4	$CFCl_3$	CF_2Cl_2	CH_3CCl_3
Mixing Ratio (Nov. 1977)	615 ppt	120 ppt	125 ppt	220 ppt	120 ppt
Lifetime (yrs)	2	100 ?	40	70	9

Odd chlorine = 2.27 ppbv

Figure 4

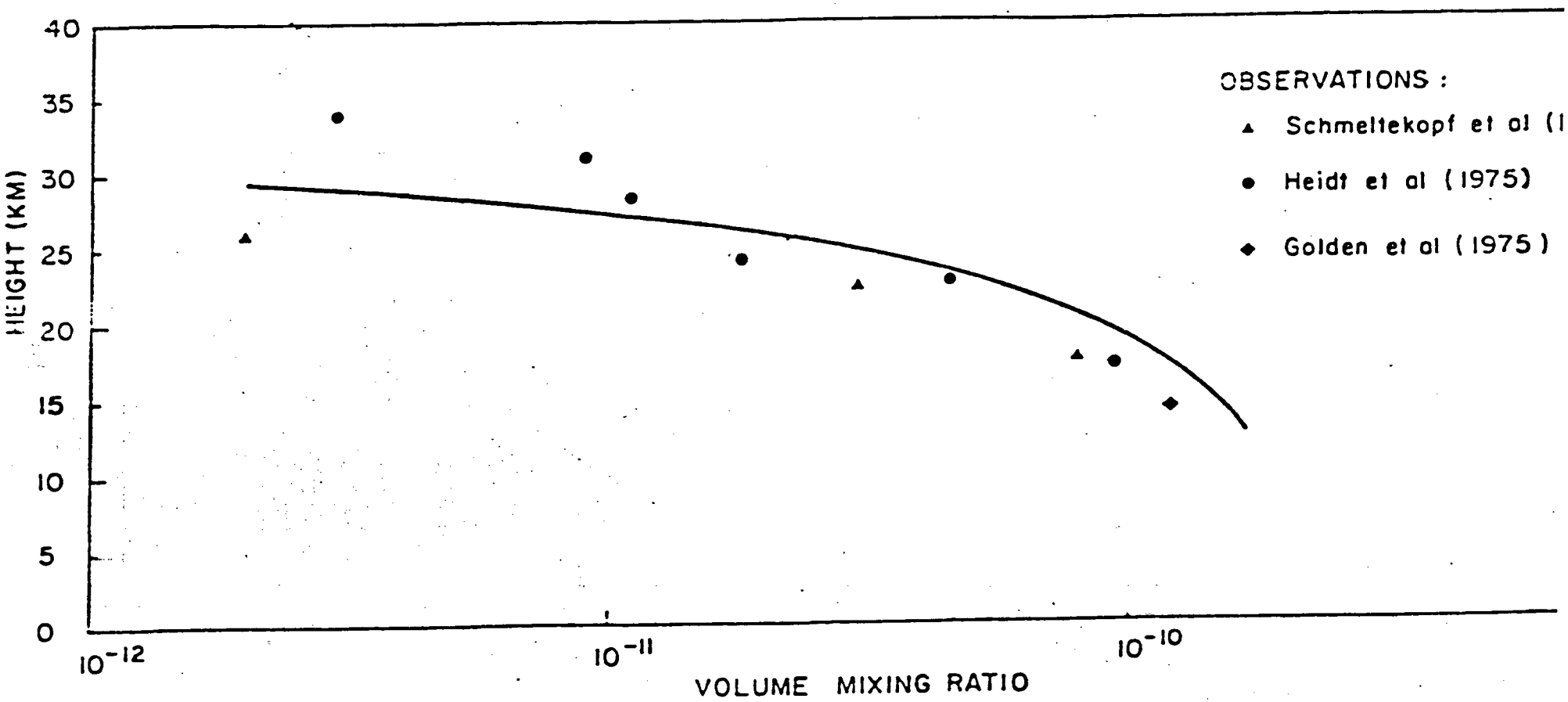


Figure 5 Comparison of the computed vertical distribution of $CFCl_3$ for 1975 at 45°N in the summer hemisphere with presently available observations.

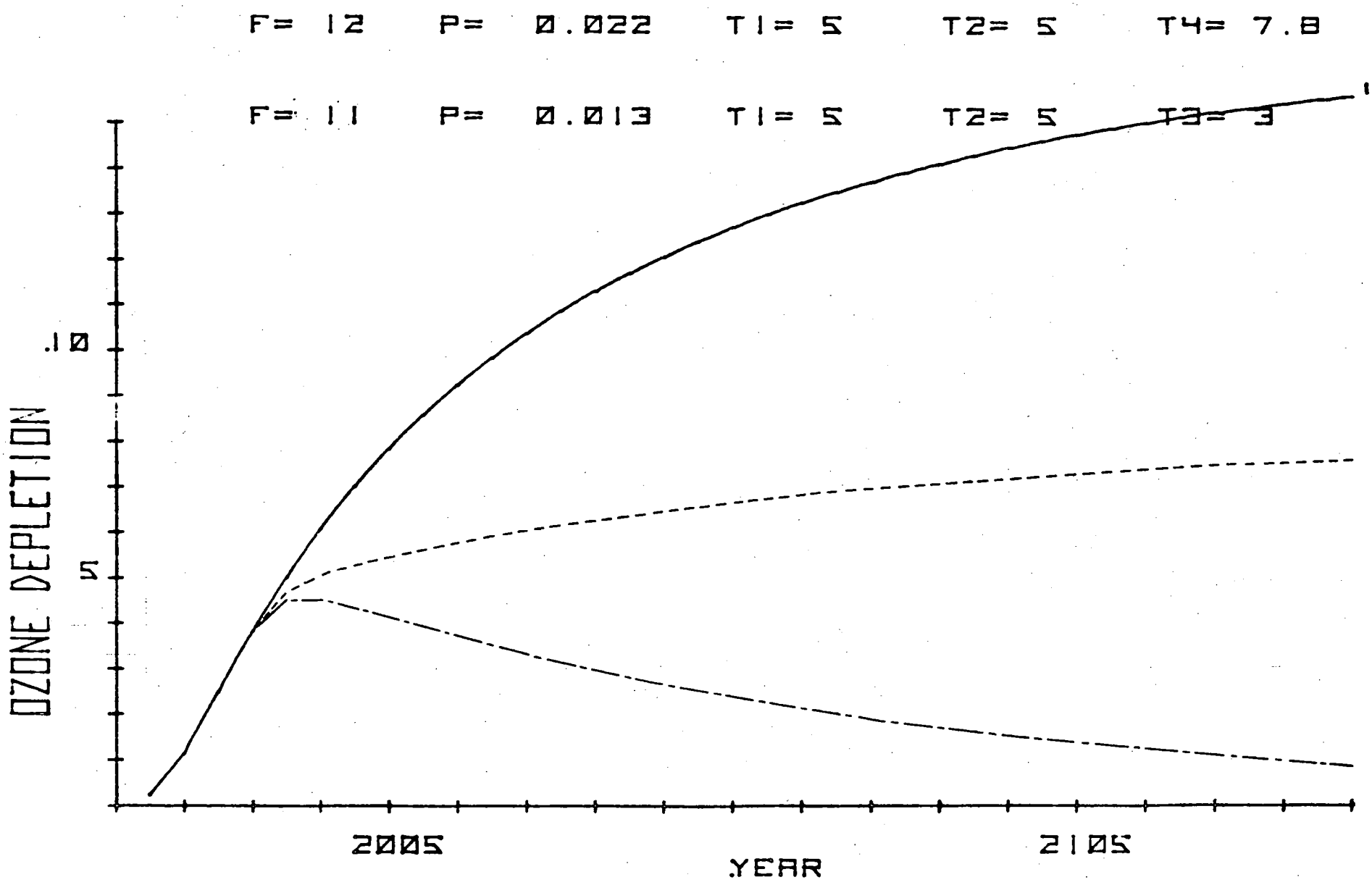

F= 12 P= 0.022 T1= 5 T2= 5 T4= 7.8
F= 11 P= 0.013 T1= 5 T2= 5 T3= 3
OZONE DEPLETION
.10
.5
2005
2105
YEAR

Figure 6

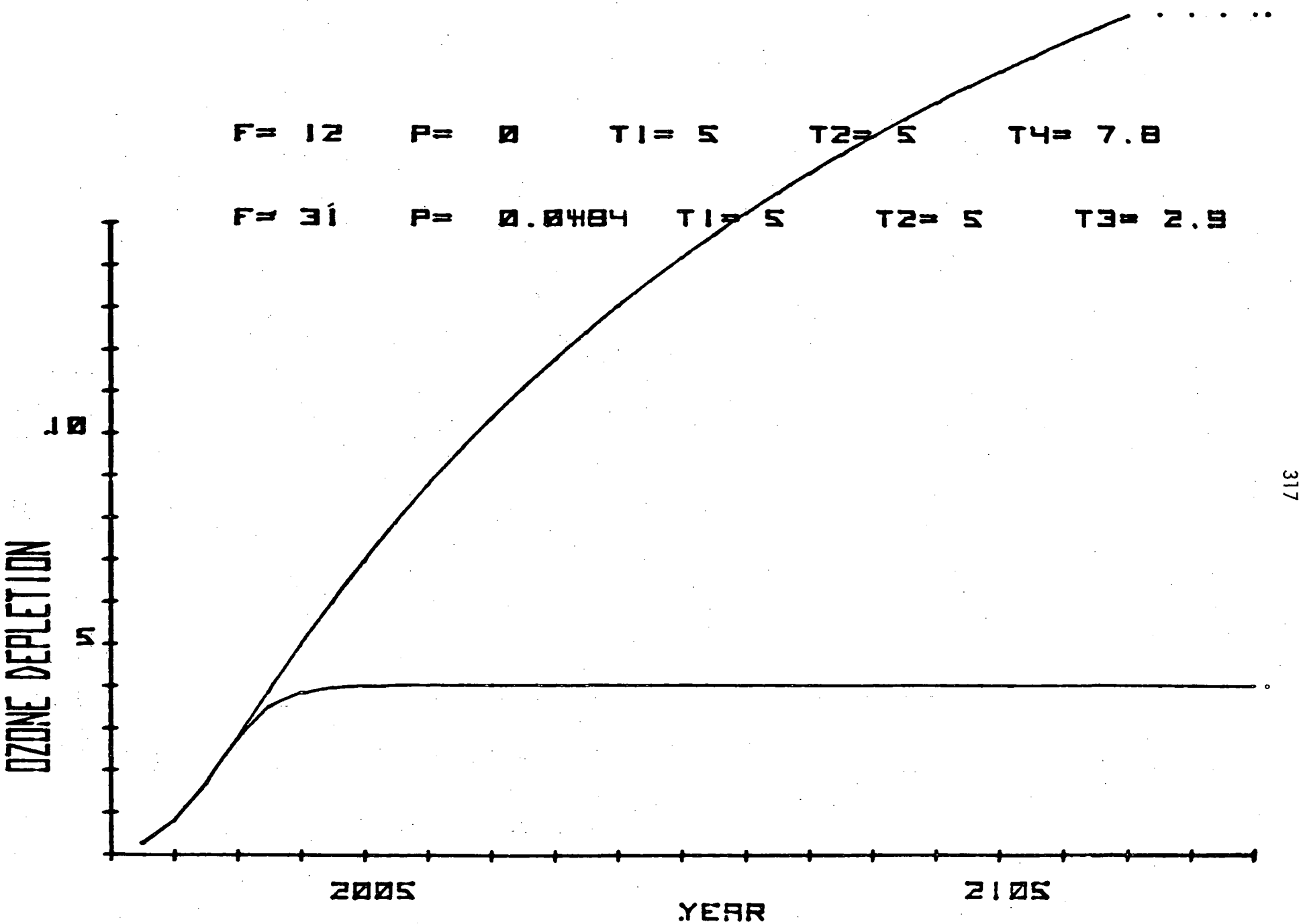

F= 12 P= 0 T1= 5 T2= 5 T4= 7.8
F= 31 P= 0.0484 T1= 5 T2= 5 T3= 2.9
OZONE DEPLETION
10
5
2005
2105
YEAR

Figure 7

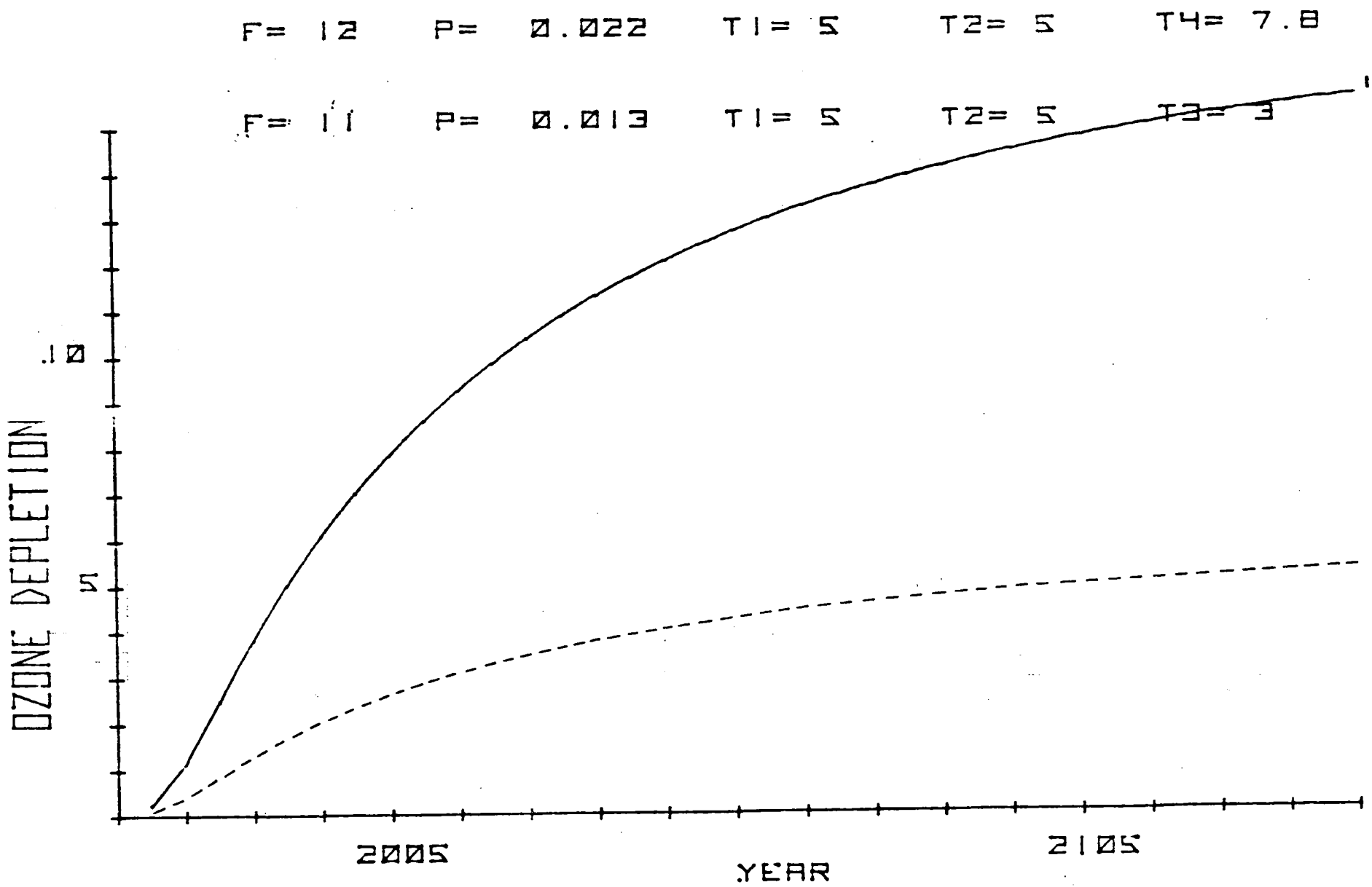

F= 12 P= 0.022 T1= 5 T2= 5 T4= 7.8
F= 11 P= 0.013 T1= 5 T2= 5 T3= 3
OZONE DEPLETION
.10
.05
2005
2105
YEAR

Figure 3

OZONE ACTIVITIES Figure 9

1. Canadian Ozone Network

Churchill Edmonton Goose Bay Resolute Toronto	Dobson - Total Ozone	Ozonesondes - 1/week

2. Publication of World Ozone Data
3. Calibration and maintenance of Network.
4. International Intercomparisons
5. Refurbishment of Dobson's for WMO
   - -Belgium
   - -China
6. Development of new Brewer Spectrophotometer
7. Ground Based Measurements of NO_2
8. Background SO_2

Figure 15 SOLAR RADIATION

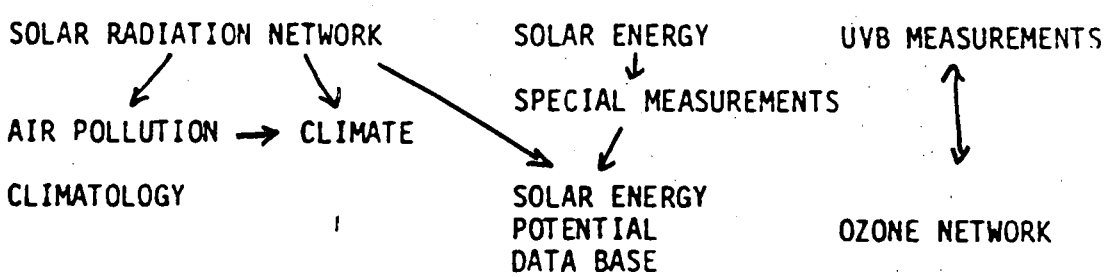
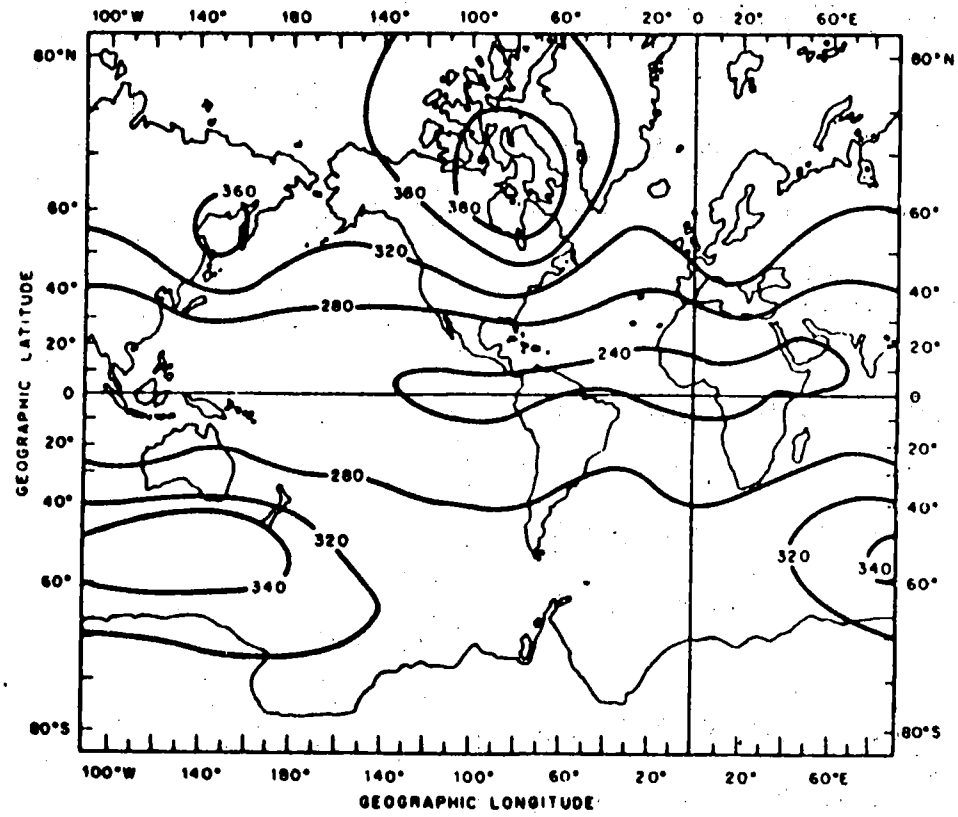


Figure 10

Global Total Ozone Distribution
(from Reference 9)



Ozone column isopleths in milliatmosphere-cm (Dobson Units).

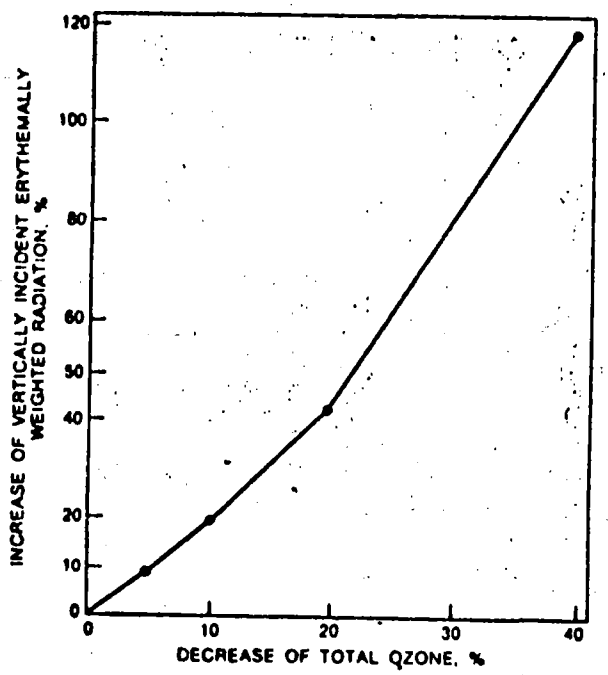


Figure 11

Percentage of change in dose of vertically incident erythemally weighted radiation vs percentage of change in ozone column. (After *Schulze*, 1973)

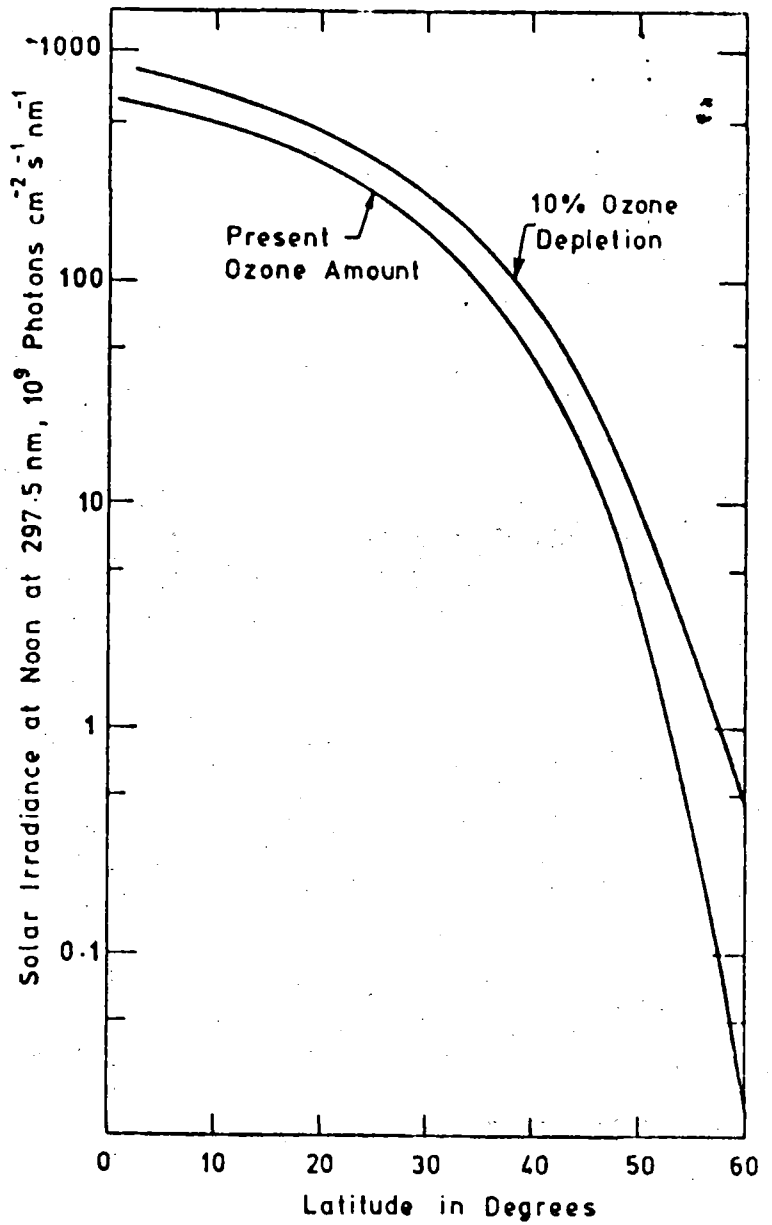


Figure 13

The effect of a 10% ozone depletion on the intensity of UV radiation reaching the ground at various latitudes in spring (Cutchis, 1974).

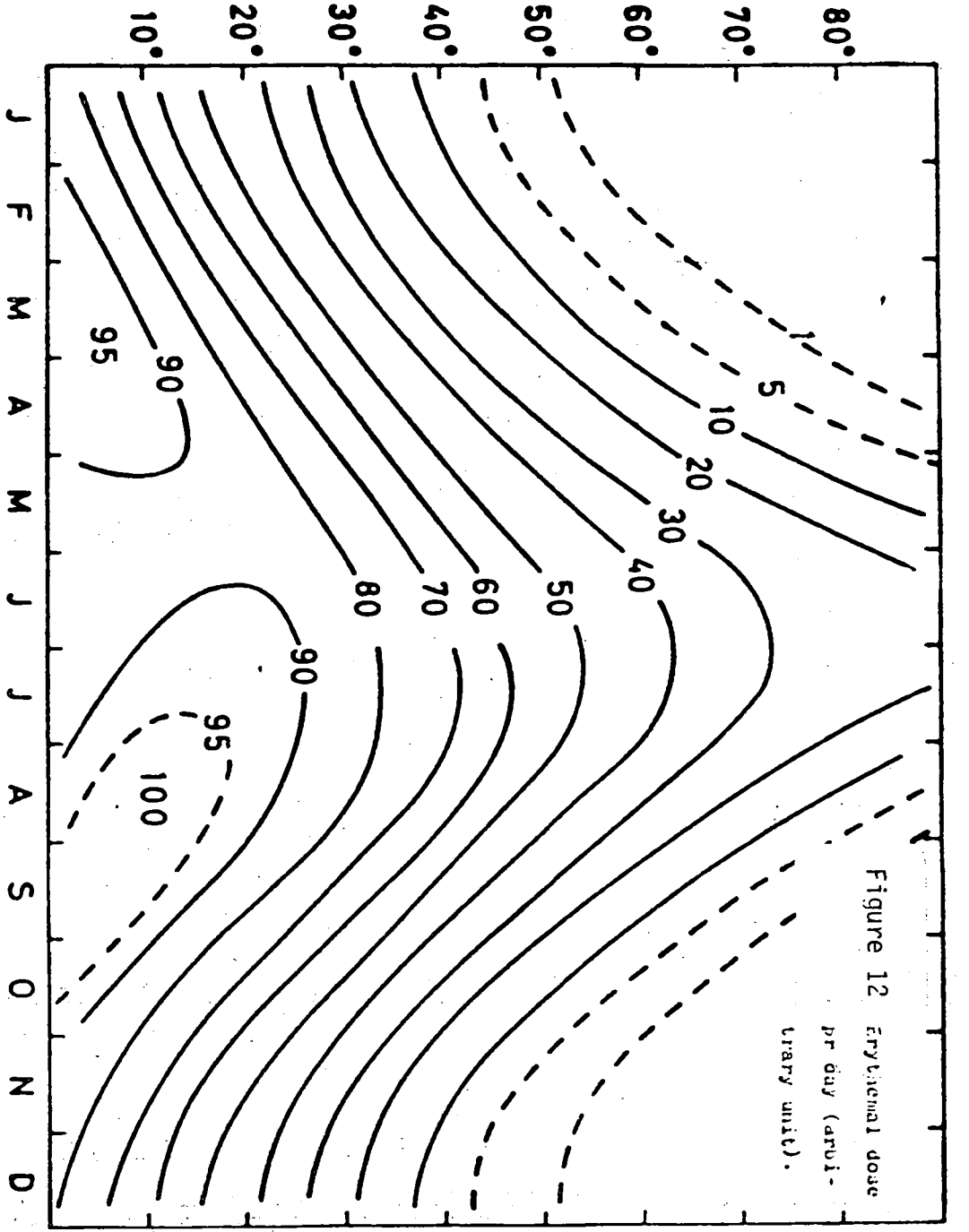
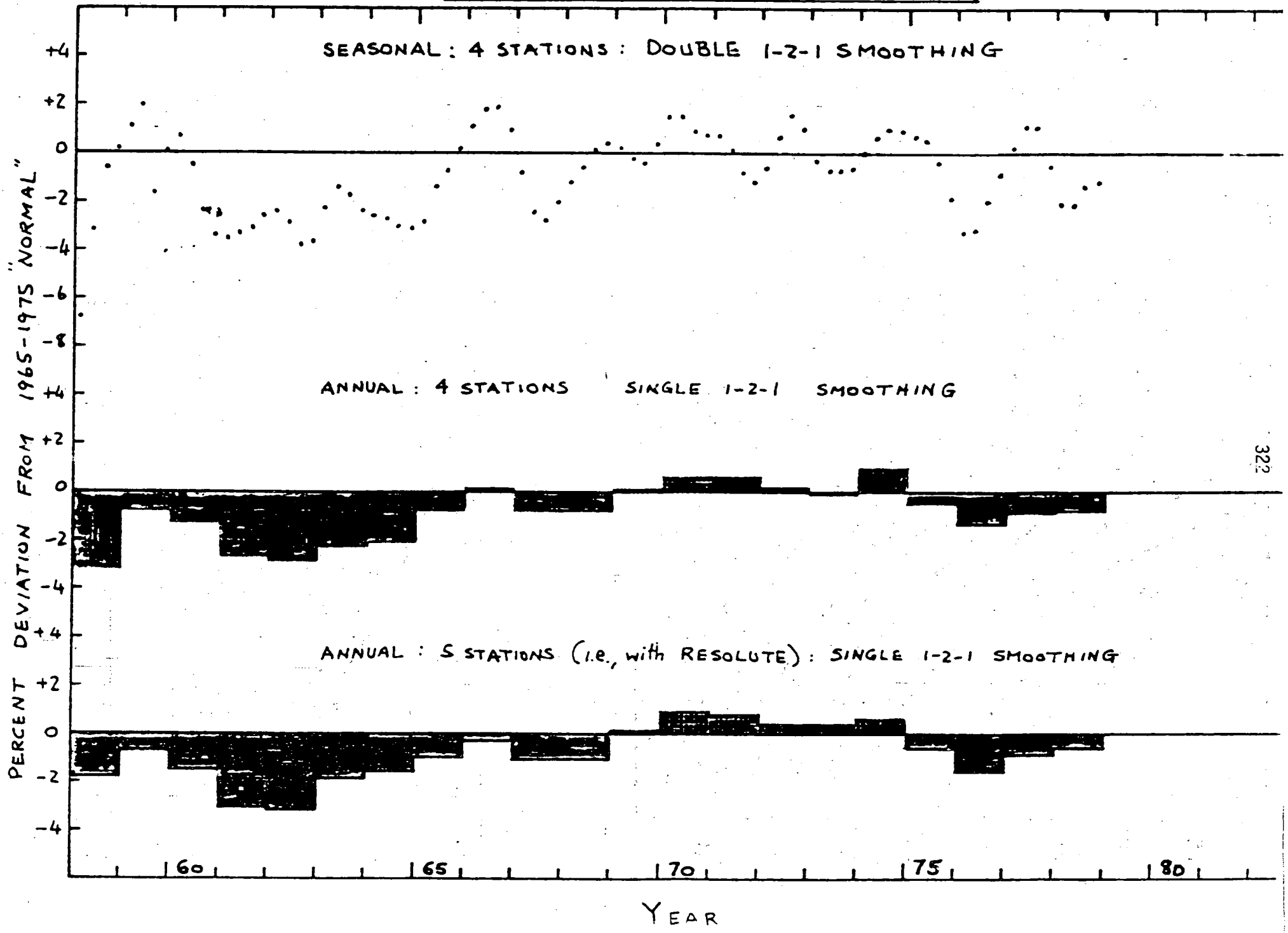


Figure 12 Erythemal dose per day (arbitrary unit).

Figure 14 OZONE TRENDS OVER CANADA



AIR POLLUTION POTENTIAL STUDIES IN CANADA

R.V. PORTELLI
E. WILSON
Air Quality Assessment Section

INTRODUCTION

The word 'potential' means something that can develop or become actual. High 'pollution potential' is then defined as a meteorological condition which, given the existence of emissions would be conducive to the development of poor air quality.

This definition is in terms of meteorological factors only: high pollution potential may occur from time to time in the arctic, for example, even when air quality is excellent. Therefore, one should not confuse the terms 'air pollution' and 'air pollution potential'.

In order to obtain quantitative estimates of pollution potential, the following have been used as climatological indices of pollution potential:

(i) Frequency of ground-based inversions,
(ii) Strength of surface winds,
(iii) Mixing height,
(iv) Transport (or mixing layer) wind speed

The product of mixing height and transport wind speed, known as the 'ventilation coefficient', is also an often used indicator of the atmosphere's dispersive capability. Areas of high pollution potential can be delineated from climatological analyses of the above factors. This information can then be taken into consideration when planning future industrial developments - especially in the North.

In the following sections, a discussion will be given of the major air pollution potential studies for Canada which have been carried out in AES.

FREQUENCY OF GROUND-BASED INVERSIONS

Munn et al. (1970) have investigated, on a synoptic scale, the climatology of surface-based inversion in Canada. Temperatures at the surface and at the first significant level above the surface for the period July 1965 to June 1968 were used to determine the frequency of ground-based inversions (including isothermal layers) at 33 sites comprising the Canadian rawinsonde network. Actually, Munn et al.'s analysis procedure identifies inversions based at or below 300 feet above the station elevation.

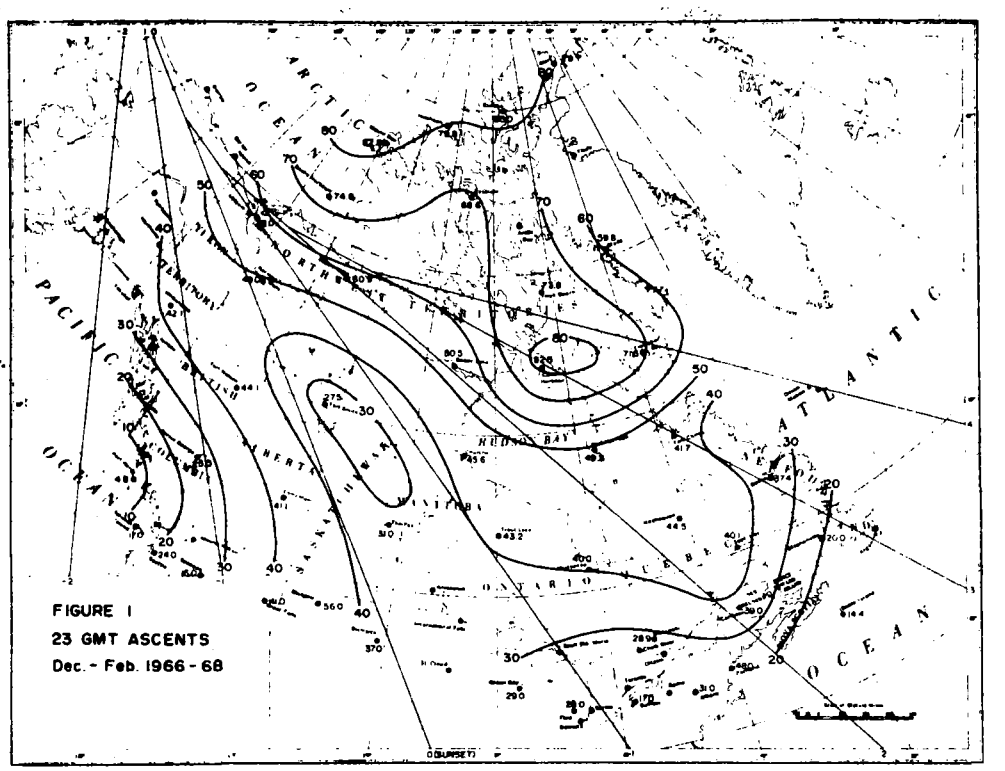
The climatological estimates of inversion frequencies were tabulated by region and are reproduced below in Table 1.

TABLE 1. Climatological estimates of inversion frequencies by region (in %), Munn et al. (1970)

	Winter		Spring		Summer		Autumn	
	Day	Night	Day	Night	Day	Night	Day	Night
Newfoundland	20	20	-	-	10-60	-	-	15
Maritime Provinces	-	35	-		-	-	-	-
Southwestern Quebec	10*	35	5*	65*	10*	90*	20*	75
Northern Quebec	-	45	-	-	8	-	-	-
Southwestern Ontario	10*	35	5*	75*	5	90*	5*	60
Northern Ontario	-	45	-	-	10	-	-	50
Manitoba	30*	55	5	60	5	70*	20*	50
Saskatchewan	-	60	3	70	4	-	-	60
Alberta	-	60	3	70	2	80	-	70
Inland British Columbia	-	50	3	60	2	80	8	65
Coastal British Columbia	-	40	3	40	5	50	10	50
Yukon	-	60	3	55	2	65	10	50
Mackenzie River Basin	-	50-65	5	60	3	-	-	50
Eastern Arctic	-	60-80	-	-	5-50	-	-	30-70

* Tower data

The data in Table 1 were inferred from seasonal day and night inversion frequency maps and some tower data. See Munn et al.'s paper for these maps; an example is given in Figure 1.



Percentage frequencies of ground-based inversions. Hours of day, relative to sunset or sunrise, are given by thin straight lines in upper or lower figure respectively.

Table 1 is the essential result of the study and it reveals a consistent seasonal cycle in inversion frequencies through

Southern Canada. Night-time inversions are most prevalent in summer and least likely in winter. The nights are shorter in summer but there is less cloudiness and lighter winds than in winter.

In their paper, Munn et al. provided a qualitative description of the inversion climatology of 8 regions of Canada, discussing average conditions and synoptic patterns that create high pollution potential. These regional descriptions are reproduced below (see original paper for references cited):

(1) The Atlantic Region

Inversions occur rarely in winter because the air is generally colder than the coastal waters, skies are frequently cloudy and wind speeds are above average. Strong-wind chimney downwash may occur rather frequently, however, unless careful attention is paid to chimney height and siting in relation to the geometry of local buildings and terrain features.

In late spring and summer at coastal locations, inversions occur frequently both day and night, associated with off-water winds. Although horizontal ventilation is often good on such occasions, vertical mixing is strongly inhibited, and the plume from a tall chimney at the coastline may fumigate to ground-level a few miles inland.

In autumn as in other parts of Eastern North America, there are occasional periods of high pollution potential caused by warm stationary anticyclones and associated subsidence inversions.

(2) Southern Quebec and Southern Ontario

Except during cloudy or windy periods, there is a regular cycle of night inversion and day lapse conditions in this part of Canada. Only rarely does a surface inversion persist for 24 hours.

Three special problems should be noted:

(i) the spring and summer lake inversion, which creates locally poor vertical diffusion within a few miles of the Great Lakes shorelines,

(ii) The warm stationary anticyclone and accompanying subsidence inversion, which occasionally shrouds the region in haze, particularly in autumn (during the Grey Cup football game at Toronto in 1962, for example),

(iii) the frontal inversion over the St. Lawrence and Ottawa river valleys, mainly in autumn and winter. Cold air is occasionally trapped in these valleys, producing a high pollution potential sometimes after only a few hours.

The occurrence of any of these three synoptic situations with sunny skies in midsummer creates high oxidant potential, e.g., Mukammal (1964).

(3) Northern Ontario and Northern Quebec

There is insufficient information in Table 1 or elsewhere to permit discussion of this region.

(4) Manitoba and Saskatchewan

These two provinces have a typically continental climate, with inversions on most nights and lapse conditions during the day. Because the underlying surface is relatively uniform, there are few local effects. The most serious pollution potential occurs in autumn and winter when a stagnant continental arctic airmass lies over the region.

(5) Alberta

The comments in (4) apply also to Alberta. There is, however, an additional synoptic pattern creating high pollution potential. The Chinook sometimes traps shallow surface pools of cold air, particularly in valleys.

(6) British Columbia

Many local effects exist in British Columbia and in Alberta on the East Slopes of the Rockies. The diffusion climatology of the Columbia River Valley has been documented by Hewson (1945) but little information is available for most other areas. Hewson's studies indicate that although ground-based radiation inversions may dissipate almost every morning (see also Table 1) the pollution potential of a deep valley may become very high during periods when there is not an adequate exchange rate with cleaner air aloft, due to a capping inversion, weak upper winds or insufficient daytime convection. At such times, pollution may drift up and down the valley over a 24-hour period with very little net transport.

Near the coast, the diffusion climatology is even more complex than inland, with interactions between sea-breezes and slope winds. The stationary

anticyclone, traditionally associated with high pollution potential, may permit the development of strong mesoscale wind flows and good ventilation at some locations. The possibility of high oxidant potential in summer should also not be overlooked.

The advice of Scorer (1968) is recommended. When undertaking a chimney-height design study in British Columbia, the local meteorologists should be consulted for information on regional and mesoscale weather patterns.

(7) The Yukon and the Mackenzie River Basin

Summer conditions in this area are similar to those in comparable (i.e., with the same terrain), parts of British Columbia and Alberta. Daytime inversion frequencies are very low and no serious pollution potential situations should develop despite the fact that inversions occur at least 60% of the time at night.

In winter, despite the long hours of darkness, night-time inversion frequencies are no greater than in summer. Because rawinsonde release times are at night (11 GMT) and near sunset (23 GMT), there is unfortunately no direct indication concerning whether inversions break up during the day, a critical consideration in deciding whether serious pollution potential develops during spells of clear skies and light winds. Indirect evidence, however, suggests that inversions may indeed persist through the day. First, there is a well-recognized winter pollution problem at Fairbanks, Alaska at the same latitude (Benson 1970) (Porteus and Wallis 1970). Secondly, winter surface temperatures in this region frequently show a small diurnal amplitude. The question is sufficiently important, however, that the recommendation is made that at Whitehorse and Norman Wells, a few supplementary early afternoon ascents be made on winter occasions when the 11 GMT temperature profile reveals an intense ground-based inversion.

(8) The Eastern Arctic

In winter, a radiation inversion may persist for days in the eastern Canadian arctic, to be interrupted only by occasional stormy periods. A ground-based inversion is to be expected 70-80% of the time, creating a very high pollution potential.

In summer, radiation inversions are absent or weak. Whenever the air has had a recent trajectory over open water or over snow and ice patches, however, there is a possibility of an advection inversion.

The potential for poor air quality is so great in this part of Canada that special precautions should

be taken to control future emissions. In particular temperature-zone methods cannot necessarily be extrapolated to arctic conditions. In the first place, chimney-height design formulae are largely irrevel- and during prolonged spells of atmospheric inversion and stagnation conditions. Secondly, because arctic vegetation and wild life are in critical equilibrium with the harsh environment, threshold pollution concentrations causing ecological damage may be lower than in the temperate zone.

In the concluding remarks, Munn et al. state that because the measurements were made at open country side locations, the regional estimates of inversion frequencies (Table 1) should not be extrapolated to locations subject to topoclimatological or urban influences. With these reservations, the study suggests that the Canadian arctic in winter is of most serious concern because of the great risk of high pollution potential. Radiation inversions may persist there for relatively long periods. Elsewhere, special problems that have been noted include the coastal advection inversion in spring and summer, the trapping of cold pools of air in the Ottawa-St. Lawrence valleys and in the Rockies, stagnant anticyclones, and the Chinook inversion in Alberta.

PERSISTENCE OF LIGHT SURFACE WINDS

The persistence of light surface winds (defined as less than or equal to 3 ms^{-1} or 7 mi h^{-1}) is one of the meteorological factors in air pollution potential. Shaw et al. (1972) examined the persistence of light surface winds in Canada in a synoptic scale study which complements Munn et al.'s study of surface-based inversions.

Hourly surface wind data were used from 111 Canadian synoptic and aviation weather stations for the period 1957-1966 and the light winds were grouped into two non-overlapping persistence classes: 24-47 hours and 48 hours and longer. For example, a light surface wind lasting 52 hours was counted only in the 48 hours plus category. Isopleth maps for Canada of the number of occurrences in each persistence class were prepared for each season; an example is given in Fig. 2.

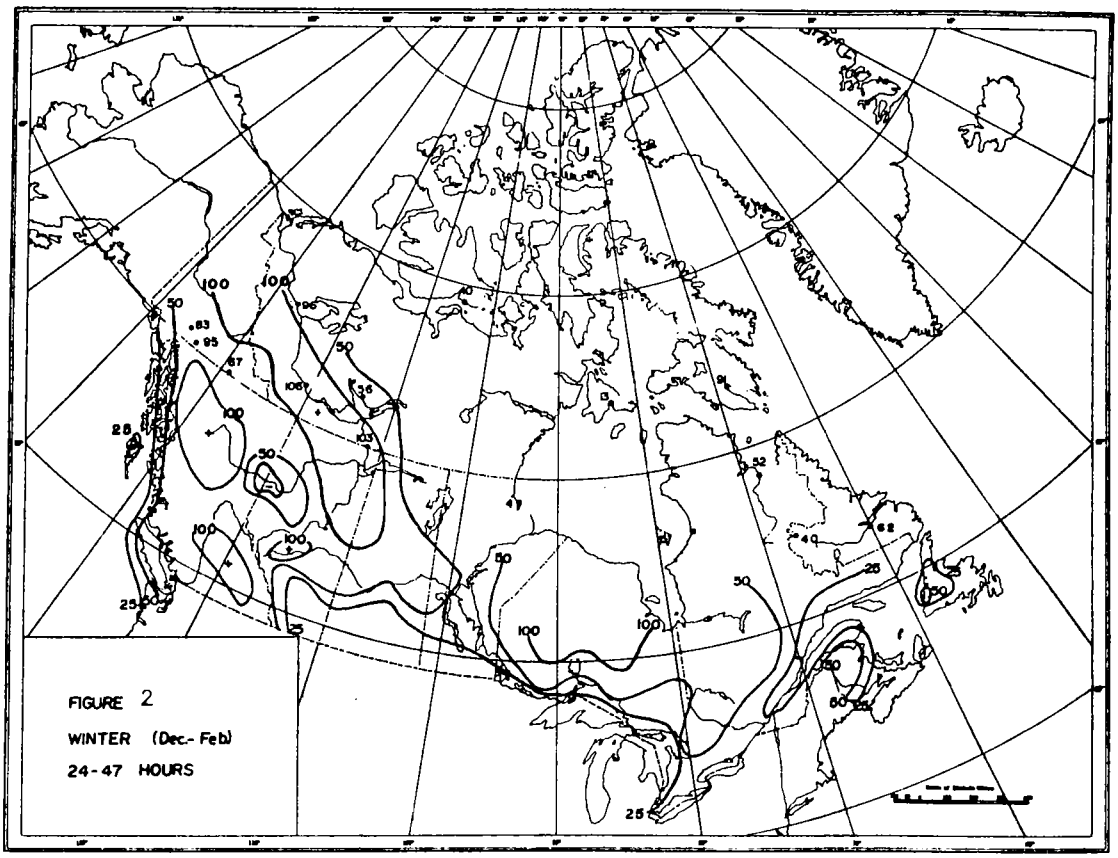


FIGURE 2
WINTER (Dec.- Feb)
24-47 HOURS

Shaw et al.'s discussion of their findings for the two persistence classes is given below:

(1) Light Winds Persisting for 24 to 47 Hours

Generally speaking, British Columbia, northern Alberta and the southern Yukon experience by far the greatest number of occurrences of light winds lasting from 24 to 47 hours. Certain regions along the Cordillera, for example, experience over 100 occurrences in 10 summers (about 4 per month) while east of the Rockies, no locality experiences that number and most have less than 25 occurrences (about once per month).

In the ten provinces of Canada the frequency of occurrence of light winds is at a minimum in the spring and increases as the year progresses from spring through summer and fall and is at a maximum in the winter. For instance, the area contained within the 100-isopleth in western Canada increases several-fold from spring to winter. However, in the Yukon and at a few available stations in the Arctic, the frequency of occurrence of light winds is at a minimum in summer rather than in spring.

In central eastern Canada, the relative spring-to-winter increase in the occurrences of light winds is even more pronounced than it is in western Canada. For instance, in the spring, almost none of Saskatchewan is contained within the 25-isopleth. As winter approaches, however, much of the central Saskatchewan is contained within the 50-isopleth, and the 100-isopleth extends as far eastward as the Alberta-Saskatchewan border. In northern Ontario, the frequency of occurrence of light winds lasting 24 to 47 hours increases from 25 to 50 and even over 100 in some areas.

An interesting minimum in the pattern occurs consistently throughout the year in Alberta. In the winter and spring it is located on the Alberta-B.C. border; in summer and fall it may be found about 200 km east of the border.

(2) Light Winds Lasting 48 Hours or Over

As found in the case for light winds lasting 24 to 47 hours, British Columbia, northern Alberta and the Yukon suffered the most from light winds lasting 48 hours and longer. In these regions the spring-to-winter increase in the number of extended ($\geq$48 hours) light wind occurrences was very pronounced in contrast to the seasonal variations of light winds lasting less than 48 hours. For example, in ten spring seasons, only certain areas in southern B.C.

> and in the Yukon experienced more than 25 occurrences of light winds lasting 48 hours or over. In ten winters, however, all of British Columbia and northern half of Alberta has had more than 25 occurrences, and extensive portions, over 100. East of Alberta, throughout the year there were relatively few occurrences of light winds lasting 48 hours or over.
>
> In the Yukon and the Northwest Territories light winds lasting 48 hours and longer occur least often in summer rather than spring, although the differences between those two seasons is not great.

It was also found that although the frequency of occurrence of persistent light winds is generally a minimum in the spring and summer and a maximum in the winter, the mean wind speed is a maximum in spring and a minimum in summer. Thus, in the summer, the winds are light but relatively steady while in the winter, strong winds are often interrupted by extended periods of light wind. The seasonal variations of light winds and of mean wind speed are shown below in Table 2.

Table 2.

	Minimum			Maximum
Frequency of occurrence of persistent light winds	Spring	Summer	Autumn	Winter
Mean wind speed	Summer	Autumn	Winter	Spring

Consideration of the synoptic weather patterns is important in understanding the above seasonal variations, particularly in the non-mountainous regions. The synoptic pattern causing light winds is the stagnating anticyclone. In the spring, there are rapid passages of frontal cyclones over Canada. The strong circulations in the cyclones ensure that the mean wind speed is high and the rapid motions of the systems mean that an anticyclone with its inherent light winds, does not remain very long over a given location. In summer, the circulations become weak and ill-defined. The mean wind speed decreases and persistent light winds occur somewhat more often than they do in the spring.

In the autumn, better-defined cyclones and anticyclones are again found over Canada but they do not move as quickly as they do in the spring. Mean wind speeds increase, but the occurrences of stagnating anticyclones and of persistent light winds also increase. In winter, Canada is often under the influence of large cold anticyclones, with frontal cyclones to the south. The passage of intense frontal cyclones, however, causes the mean wind speeds to be high.

The conclusions drawn from this study are given below:

> Generally speaking, persistent light winds (those lasting from 24 to 47 hours and 48 hours and over) occurred most frequently in British Columbia, the Yukon and northern Alberta. In the ten provinces, they occurred most frequently in the winter months and least often in the spring. In the Yukon and at the few available stations in the Northwest Territories, persistent light winds occurred least often in the summer. The seasonal variation was less pronounced in British Columbia, the Yukon and northern Alberta and more pronounced in the rest of Canada. Therefore, the contrast between western Canada and the rest of the country was less in winter than in spring.
>
> The spatial and seasonal variations in persistent light winds suggest that, in the mountain valleys, topography is the major factor, while in other regions synoptic weather patterns are more important.
>
> Due to the sparseness of data, general conclusions could not be drawn about the Arctic. However, at two locations from which data are available (Frobisher and Cambridge Bay) light winds lasting 24 to 47 hours occur on the average 2 to 4 times per winter month and may contribute to a high pollution potential.

It is also important to note that in applying this regional information to specific localities, account must be taken of important local effects such as those caused by large bodies of water, by urban development and by topographic features.

MIXING HEIGHTS, WIND SPEEDS AND VENTILATION COEFFICIENTS

Mixing height and wind speed are the paramenters commonly used in studying pollution potential as they determine the volume through which pollutants are mixed and diluted. The maximum mixing height is defined as the height above the surface where the dry adiabatic extension of the surface maximum afternoon temperature intersects the 1200 GMT temperature profile as shown in Fig. 3.

Portelli (1977) has prepared a Canadian climatology of mixing height, mean transport wind speed in the mixed layer, and ventilation coefficient. Rawinsonde data from 33 Canadian and 13 U.S. stations were analysed to produce monthly tabulations of daily values of maximum (afternoon) mixing height, wind speed in the mixed layer and ventilation coefficient for the 4-year period July 1965 to June 1969.

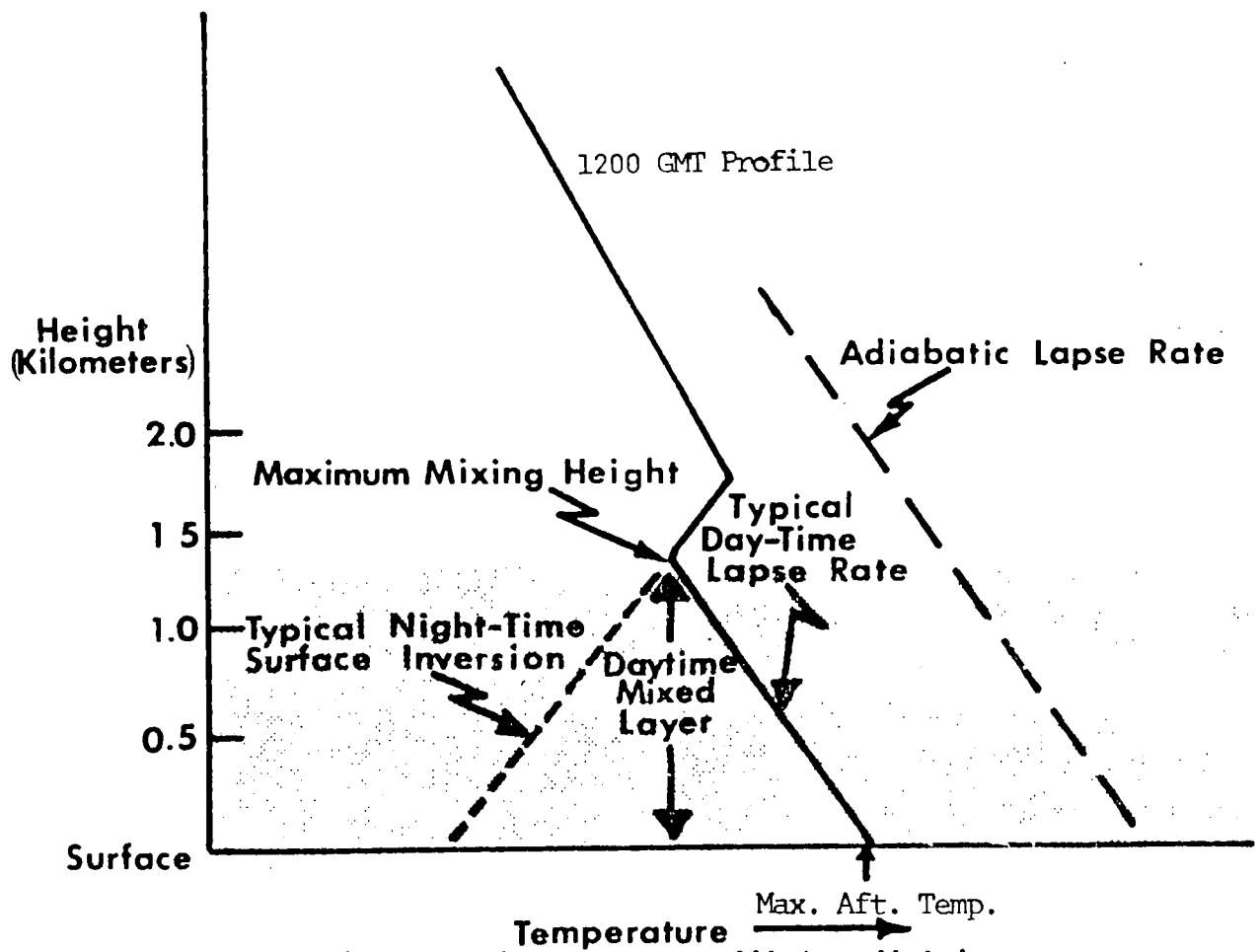


Fig. 3 **Calculation Of Maximum Mixing Height**

The major assumption of the mixing depth method is that vertical mixing is a function only of the vertical temperature

structure at the time of the sounding and surface maximum temperature. Thus, it is evident that maximum (afternoon) mixing depths are not overall indices of pollution potential but must be used in conjunction with other factors, such as wind speed.

The observed wind speeds in the mixed layer (0000 GMT profile) are averaged to provide a mean mixing layer wind speed. The wind direction at mid-height is taken to be representative for the layer. The ventilation coefficient (m^2s^{-1}) is then obtained from the product of the mixing height and the mean wind speed.

The typical seasonal variation of mixing height, wind speed and ventilation coefficient at an inland continental site are: high mixing heights in summer, low in winter; high wind speeds in spring and fall, low in winter; high ventilation coefficient in summer, low in winter. The mixing height trend, however, is somewhat reversed at a coastal location - particularly an offshore location such as Sable Island, due to the coastal advection inversion which suppresses summer mixing heights.

Isopleth maps were prepared for Canada from the mean seasonal and annual values of mixing height, wind speed and ventilation coefficient. Fig. 4 and 5 exhibit the mean annual mixing heights and wind speeds. High pollution potential regions are depicted by low values.

The following is extracted from the summary and conclusions of Portelli's (1977) study, for more detail see original report:

> This study provides estimates of mean maximum mixing heights average mixing layer wind speeds and maximum ventilation coefficients for Canada from regular upper-air observational data. The mixing heights display the greatest seasonal variation at inland locations and least in areas adjacent to large bodies of water; the deepest mixing layers generally occurring in summer (range - about 400 to 2100 m) and shallowest in winter (range - about 100 to 600 m). In summer, limited vertical mixing conditions occur whenever winds blow inland from oceans, large lakes and (in the Arctic) from snow or ice-covered surfaces to bare ground, while in winter, winds off unfrozen waters tend to increase mixing depths over land. Also, the Chinook winds and a stagnant continental arctic airmass contribute to limited mixing conditions just east

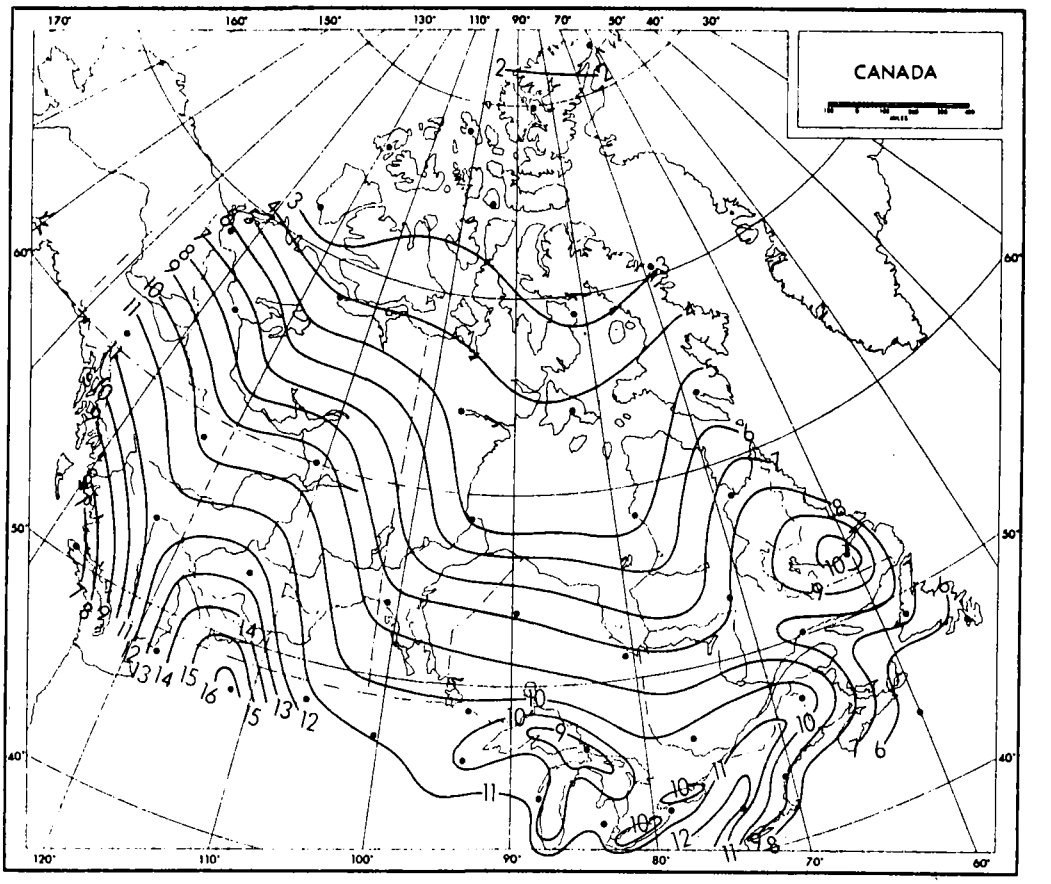


Figure 4 Isopleths (m x 10²) of mean annual maximum (afternoon) mixing heights

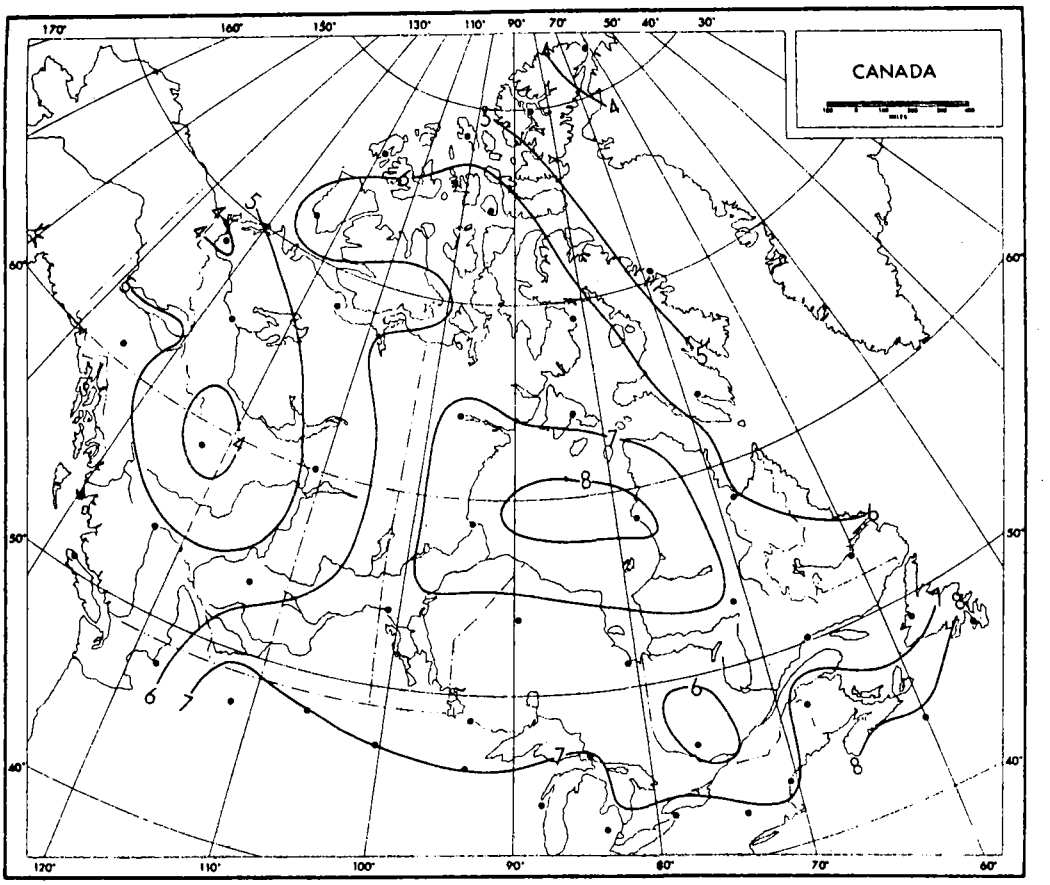


Figure 5 Isopleths (m sec⁻¹) of mean annual wind speed averaged through the maximum (afternoon) mixing layer

of the Rockies during winter. The region with the most restricted mixing depths throughout the year is the Arctic whereas the most unlimited mixing heights typically occur over the Columbia Mountains.

The mean mixing layer wind speed exhibit relatively small seasonal variations; high values normally occur in the regions of Hudson Bay and the Atlantic provinces and low values occur in the high Arctic and in a region centered about Fort Nelson extending from Inuvik to about Edmonton - encompassing the MacKenzie Valley. The highest and lowest mean wind speeds occur during the winter months in the Atlantic provinces (up to 10 m/s) and the region about Fort Nelson (down to 2 m/s), respectively.

Maps of mean maximum ventilation coefficients generally display isopleth patterns that are quite similar to those of the maximum mixing heights. The highest ventilation coefficient values generally occur in summer (range - about 2000 to 15000 m^2/s) and the lowest in winter (range - about 500 to 600 m^2/s); shoreline locations experience relatively low values in summer and the reverse in winter. Areas with meteorological potential for pollution are considered to be those with ventilation coefficient values of not more than 6000 m^2/s. During summer, such conditions are found in northern Canada (over most of the Arctic) as well as in the coastal zones, but during winter, such is the case for almost all of Canada.

In applying these regional estimates of mixing heights, wind speeds and ventilation coefficients to specific locations, (via interpolation or extrapolation) close attention must be given to mesoclimatological influences, especially over irregular terrain, since these estimates are based on observations in open rural settings. With this in mind, the present study indicates that the Canadian Arctic has significantly high meteorological potential for pollution - especially in winter - due to the severely restricted dispersal capacity of the atmosphere. In winter, a region of considerably high potential extends down from Inuvik and the MacKenzie River Basin to southeast of Edmonton due to the Chinook inversion just east of the Rockies and the prevalence of quasi-stationary anticyclones in the area. Serious concern is warranted here in light of current and proposed industrial developments in this region. Also of significance, are the coastal advection inversions found in British Columbia and the Atlantic provinces which create limited mixing conditions.

The second phase of the Canadian mixing depth study which is nearing completion is the analysis of joint frequency distributions of the mixing depth parameters. From the tabulations of daily values of mixing heights, mean wind speeds through the mixed layer and ventilation coefficients, for the period July 1965 to

to June 1967, the following joint-frequency distributions have been prepared on a monthly and annual basis for each of the 46 stations:

(i)	Mixing Height	vs	Wind Direction
(ii)	Mixing Height	vs	Wind Speed
(iii)	Wind Speed	vs	Wind Direction
(iv)	Ventilation Coefficient	vs	Wind Direction
(v)	Ventilation Coefficient	vs	Wind Speed

For each of the 46 stations, there are 65 tables in all (i.e. 13 monthly and annual distributions x 5). These number frequency distributions have been placed on microfiche such that a single fiche exists for each station with all 65 tables contained. Similar tables have been prepared in percent frequency (rather than number frequency) on a monthly, seasonal and annual basis. A sample is given in Table 2. At the moment these are available in paper copy only, not on microfiche.

Table 2.

23/08/78 PERCENTAGE FREQUENCIES OF JOINT OCCURRENCES OF MAXIMUM MIXING HEIGHT VS. WIND DIRECTION PAGE 13

TOTAL FILE JULY ,65 - JUNE ,69 NO OF DAYS 1461 25004 THE PAS MAN ELEV 273

WIND DIRECTION (DEGREES/10)		MAXIMUM MIXING HEIGHT (METERS) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
						1 TO 199	200 TO 399	400 TO 599	600 TO 799	800 TO 999	1000 TO 1199	1200 TO 1399	1400 TO 1599	1600 TO 1799	1800 TO 1999	2000 +	SUM COL 3-15	SUM COL 1-15
	M	0.0	0.0	0.0	0.0	0.0	.1	.1	.1	.1	0.0	.1	0.0	.1	0.0	.1	.7	.7
2	C	0.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1
3	U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	CALM	0.0	0.0	0.0	0.0	.7	.5	.3	.1	0.0	.1	0.0	.1	.1	.1	0.0	1.8	1.8
5	01-04	0.0	0.0	0.0	.1	1.1	1.4	1.5	.6	.8	.4	.2	.3	.2	0.0	.1	6.8	6.8
6	05-08	0.0	0.0	0.0	.1	1.4	1.6	.9	.3	.1	.1	.3	.2	.1	.1	.1	5.3	5.3
7	09-12	0.0	0.0	0.0	.1	1.4	2.0	1.3	1.0	.2	.3	.3	.4	.2	.2	.1	7.4	7.4
8	13-16	0.0	0.0	0.0	0.0	1.2	4.0	1.7	1.5	1.0	.7	.8	.1	.3	.1	.6	12.1	12.1
9	17-20	0.0	0.0	0.0	.1	.3	2.1	1.2	.5	.5	.8	.6	.3	.4	.7	.5	8.1	8.1
10	21-24	0.0	0.0	0.0	0.0	.5	1.1	.9	.5	.6	.7	.6	.3	.3	.2	1.2	6.9	6.9
11	25-28	0.0	0.0	0.0	.1	1.2	3.1	1.4	1.8	1.1	.8	1.0	.9	.5	.9	2.1	14.9	14.9
12	29-32	0.0	0.0	0.0	.1	2.0	3.2	2.7	2.0	1.8	1.0	1.4	1.4	1.0	.5	2.1	19.2	19.2
13	33-36	0.0	0.0	0.0	.1	1.1	1.6	1.3	1.0	1.1	.5	.8	.5	.6	.4	.5	9.7	9.7
14	SUM ROW 4-13	0.0	0.0	0.0	.8	10.9	20.5	13.3	9.2	7.2	5.3	6.0	4.5	3.8	3.2	7.5	92.2	
15	SUM ROW 1-13	0.0	7.1	0.0	.8	10.9	20.7	13.3	9.3	7.3	5.3	6.2	4.5	3.8	3.2	7.5	92.9	100.0

M - MISSING & DEFAULT
U - UNLIMITED MIXING
C - COLD AIR ADVECTION

SUM OF ALL MIXING HTS.= 1146853.0 NO OF CASES = 1357 MEAN = 845.1
SUM OF ALL MIXING HTS. (ROW 4-13)=1136882.0 NO OF CASES = 1347 MEAN = 844.0

INDIVIDUAL	65	843.4	66	797.5
YEARLY	67	875.3	68	852.1
MEANS	69	868.3		

A sample of how this data can be used is given in Fig. 6. This is an analysis of the Annual Percentage Frequency of Ventilation Coefficients less than 1000 m^2/s, and corresponds to the occurrences of the most seriously restricted horizontal and vertical diffusion.

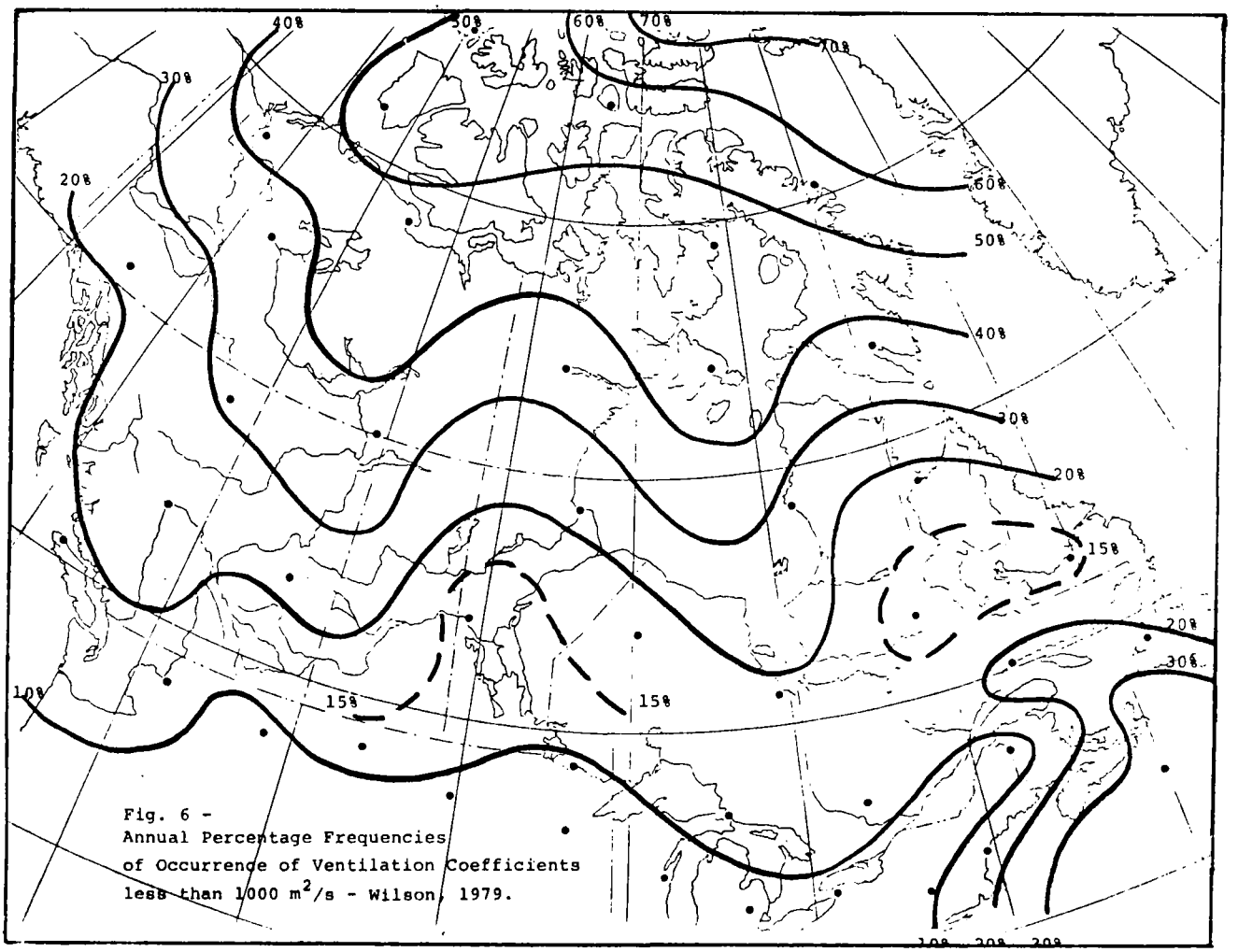


Fig. 6 - Annual Percentage Frequencies of Occurrence of Ventilation Coefficients less than 1000 m^2/s - Wilson, 1979.

1. The greatest percentage frequency occurs across the High Arctic. This is a result of a combination of low annual mixing heights and a high frequency of light mean winds through the mixing layer. (Note: The 'mixing depth' concept is most applicable to mid-latitudes, and does not recognize the peculiarities of the Arctic such as the almost constant surface-based inversion in winter.)

2. A 'trough' of relatively higher frequencies extends along the MacKenzie Valley, and northern and eastern Alberta to the lee of the Rockies. Lower conditions are more frequent due to cold air trapped in valleys and the outflow against the mountains from the Arctic high pressure ridge from fall to spring.

3. Secondary 'troughs' protrude across the Hudson Bay and from the Atlantic coastal waters into the Gulf of St. Lawrence, reflecting the marine inversions from spring to early fall.

4. Lower relative frequencies are evident in the 'shadow' of the Rockies (southwestern Alberta). Greater surface heating and stronger winds in the lee subsidence zone are the major contributing factors.

5. Similarily, relatively lower frequencies are found over the prairies (Manitoba) and the central Quebec-Labrador land masses. Greater surface heating occurs from spring to early fall compared to the surrounding maritime regions.

From the analysis of the frequency patterns and reference to previous studies, twelve regions with similar pollution potential have been identified. The following table lists the regions in order of their average annual frequencies of ventilation coefficients less than 6000 m^2/s. (The U.S. Air Pollution Forecast program identified 6000 m^2/s as the threshold value for <u>high</u> pollution potential - this U.S. value is being used as a relative indicator for regional comparisons in Canada):

1.	High Arctic	96.2%
2.	Baffin	84.1
3.	Pacific	81.9
4.	Mackenzie Valley	78.5
5.	Hudson Bay	77.6
6.	Atlantic	72.0
7.	Prairies	61.3
8.	Central Quebec - Labrador	59.6
9.	Rockies	56.3
10.	Great Lakes	55.1
11.	Lee of the Rockies	49.9
12.	Appalachians (Northern N.B.)	45.0

On an annual basis, almost 50% or more of the average annual occurrences are in this range in all regions of Canada. Coastal regions and the Mackenzie Valley have the highest frequencies, (>70%).

A report is currently being prepared on the above study by E. Wilson.

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DISCUSSION/COMMENTS

R.M. HOFF: Evelyn, you mention that 6000 metres square per second, (as a ventilation coefficient) was accepted in the States as a threshold point for air pollution problems, but I noticed on the next to the last transparency that in the Summer in Canada, there are a fair number of regions we would identify as having an air pollution problem, that are less than that 50% of the time. Do you think that's reasonable for Canada to use that number?

E. WILSON: No, I don't think so, especially in the winter, when you can see that almost over 70% of the cases of all regions in Canada fall in that category. I think a process of examining the different levels for each region may be necessary. Again, we have a problem in the high Arctic where the whole mixing depth concept could run amuck, so I have to take a look at that area again probably with respect to different parameters relevant to the ventilation coefficients.

R. GABISON: What parameters did you use in defining the mixing height? How were these measurements really taken? In the context of the possible applications of mixing heights, this is a very important parameter also in the study of modelling of atmospheric dynamics such as heat fluxes, moisture fluxes and momentum fluxes. I would like to have your answer on the first two questions.

E. WILSON: The mixing depth concept is, as defined by Holsworth in 1967 as follows: You take the 12 GMT vertical temperature profile, then from the local maximum surface temperature extend dry adiabatically to the intersect point, and this is the afternoon mixing height that was used in the study. The mean wind speeds through the mixed layer were taken at 00 GMT and were averaged from the surface up to the base of the mixing height. Ventilation coefficient is then the product of both of these parameters. Regarding the second question, this is essentially what Ron Portelli had described earlier. He also used basically the same data set in his report, and this was taken from 33 Canadian radiosonde stations, and 13 U.S. border stations over a period of 4 years, from July 1965 to June 1969.

R. GABISON: Is that station data or is it analysed to grid points?

E. WILSON: Station data, yes.

R. GABISON: So they are essentially representing the station data values from which you are attributing the regional characteristics.

E. WILSON: Well, yes. This depends on the region. I have averaged the information over the region according to the frequency patterns. Now, each of the frequency patterns of the different levels of mixing heights identified regional characteristics, and averaging those values over that region gives you an idea of what's happening with respect to that region. Now certain regions certainly have limited data like Port Hardy on the Pacific Coast.

URBAN AIR POLLUTION PROBLEMS

M.M. MILLAN
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Abstract: Because of their terrain features such as roughness, albedo, etc., their location and their characteristics as a source of heat and pollutants, cities present certain unique air pollution problems. These will be addressed for an idealized city and further generalized for various typical terrain locations.

(Paper not received)

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PROJECTS ON THE CHEMICAL AND BIOLOGICAL ASPECTS OF AIR POLLUTION

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INTRODUCTION

The Atmospheric Chemistry, Criteria and Standards Division (ARQA) has been engaged in research on the chemical and biological aspects of air pollution. This article will attempt to give a cursory outline of some of the projects. In this way, the reader will obtain an overall view of ARQA research activities (and facilities) at AES Headquarters.

OXIDANTS IN THE TORONTO REGION

In the summer of 1975, ARQA carried out a detailed study of ozone formation in the Toronto region; this included ground-level sampling stations and an aircraft survey. The goal was (i) to identify the major features of the photochemical formation of ozone and (ii) to identify the significant meteorological conditions conducive to ozone formation or its transport.

The study identified three typical meteorological conditions that are conducive to high ozone (oxidant) formation in the Toronto region:

(i) the stagnation of an anticyclone over the lower Great Lakes region can lead to very high ozone with mid-afternoon concentrations of 200-250 ppb.

(ii) a regional southerly flow as generated behind an anticyclone system can lead to ozone concentrations in the range of 100-150 ppb.

(iii) during a lake breeze, ozone concentrations are similar to case (ii).

For cases (i) and (iii), locally emitted pollutants are primarily responsible for the build-up of ozone. However, in case (i) ozone levels are high over a large part of southern Ontario whereas during lake breeze days with regional northerly

flows, high ozone is confined to a lake breeze 'cell'. For case (ii), the transport of ozone and its precursors from urban areas to the south of Toronto is responsible for high ozone concentrations. It should also be noted that for northerly flows (typically before an anticyclone system has reached the lower Great Lakes), ozone concentrations were low (about 40-60 ppb), indicative of clean air.

Figure 1 shows a plot of daily ozone maxima for Toronto Island and Wesleyville - an Ontario Ministry of Environment station about 80 km to the east. Examples of the three types of cases (i) to (iii) discussed above are designated by the Roman numerals I, II and III respectively. Some examples of the information made possible by the aircraft survey are shown in the next two figures. Figure 2 shows an example of regional southerly flow, case (ii); it is readily evident that ozone levels are relatively high (100-150 ppb) over the whole region and that it is well-mixed up to the inversion layer. Figure 3 shows case (iii), a lake breeze day. On this day, the regional winds were northerly but sufficiently weak for a lake breeze to develop. The figure shows the change in wind direction with height as well as the O_3 concentration profile. There are high O_3 levels over Lake Ontario but low concentrations to the north of Toronto at Holland Marsh or Stouffville. (The sharp decrease in the O_3 at low altitude near Toronto was caused by NO scavenging as the aircraft crossed a power plant plume during its spiral).

Figure 4 shows an interesting comparison of hourly ozone concentration at four stations on August 9 -- a day of persistent regional southerly flows. It is readily apparent that even though over 90% of all photochemical activity has ceased by 1800 hours, the ozone decays very slowly and is high even late at night -- indicative of ozone transport from regions upwind.

For more detailed discussions on the formation and transport of ozone, the reader is directed to the references and other papers of this workshop.

In passing it is worthwhile to draw the reader's attention to another ARQA chemistry program -- the air and particulate

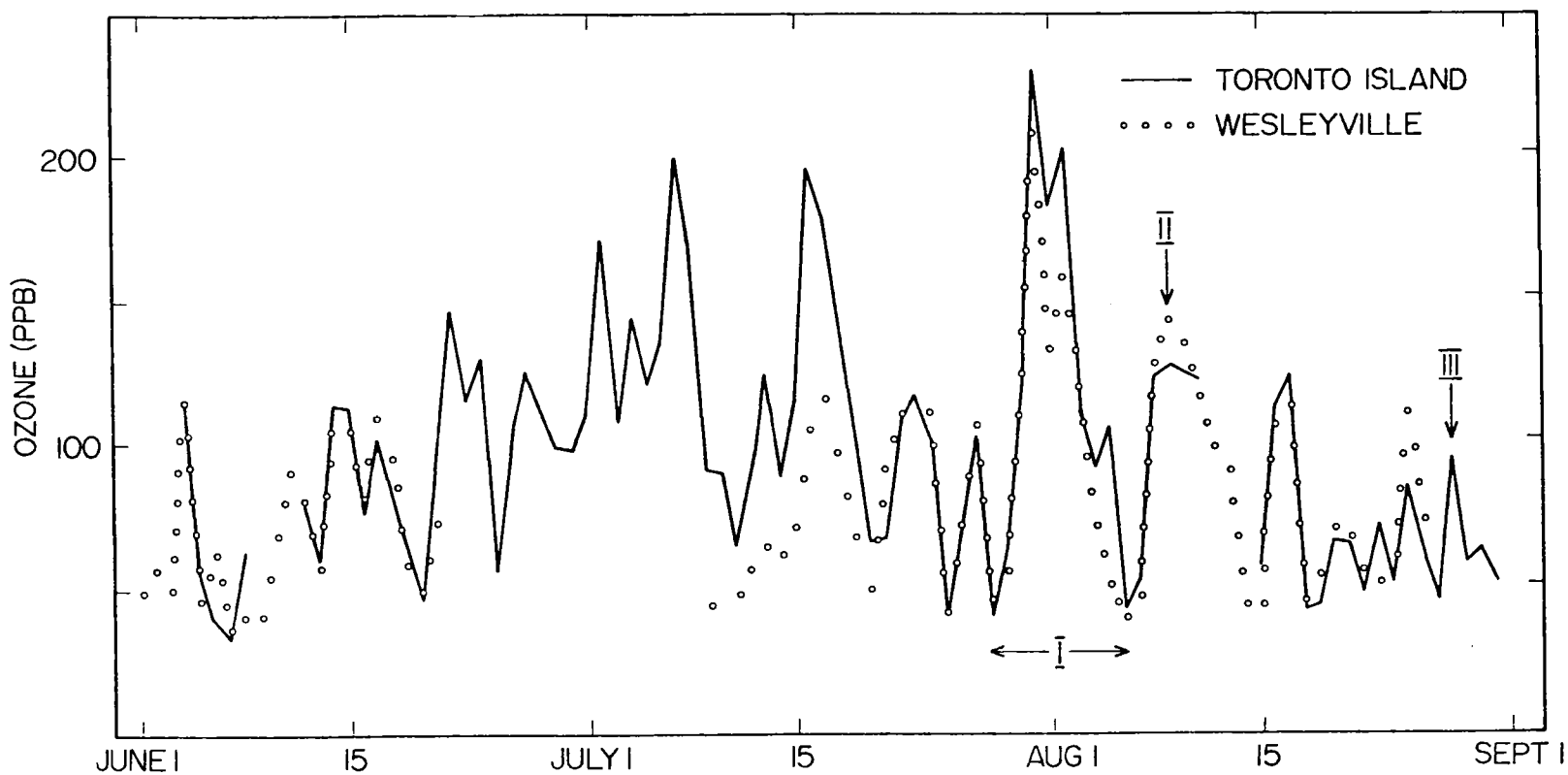

FIGURE 1: Daily hourly average ozone maximum at Toronto Island and Wesleyville, 1975.

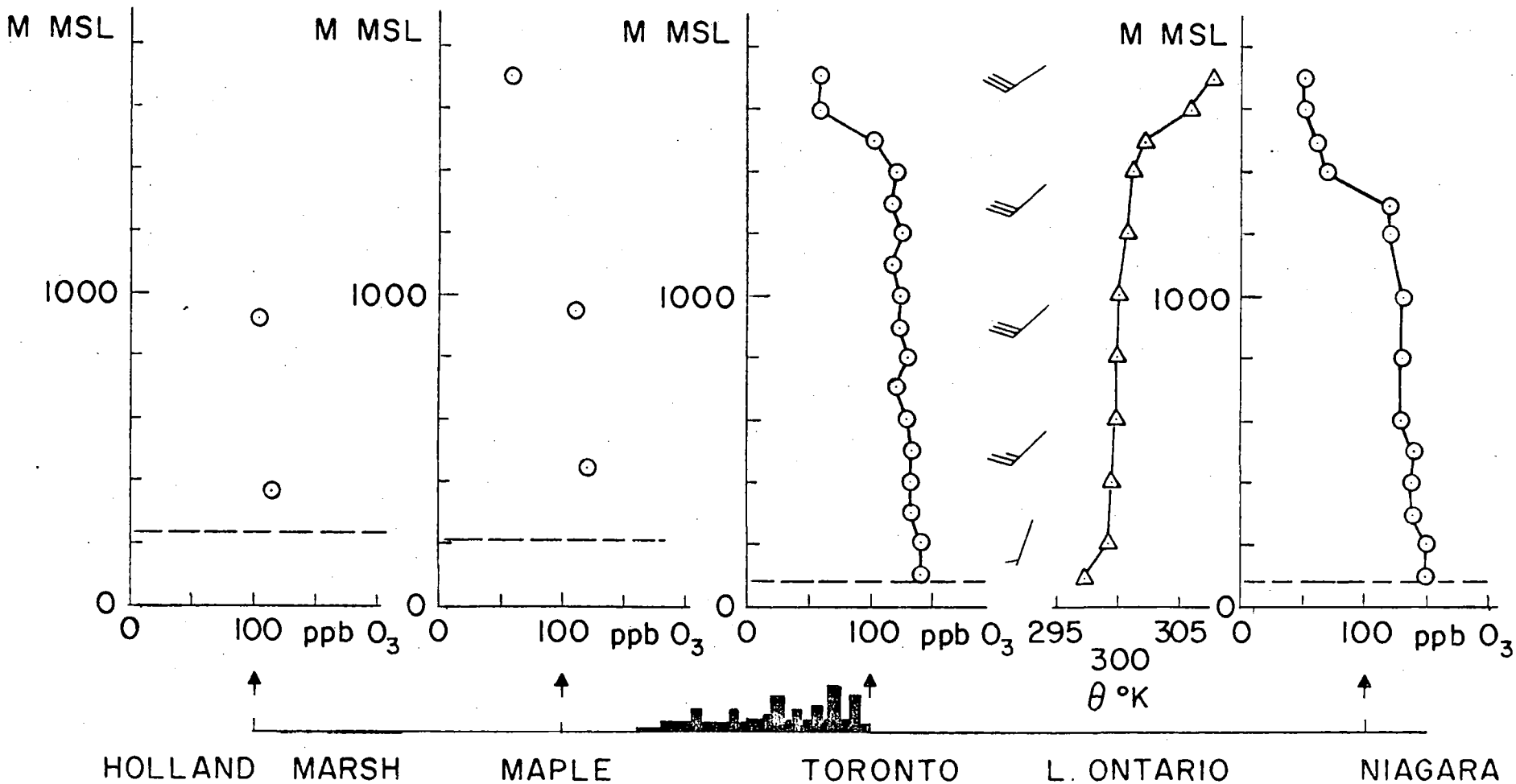

FIGURE 2: Aircraft ozone measurements on August 9th, 14-16 EST.

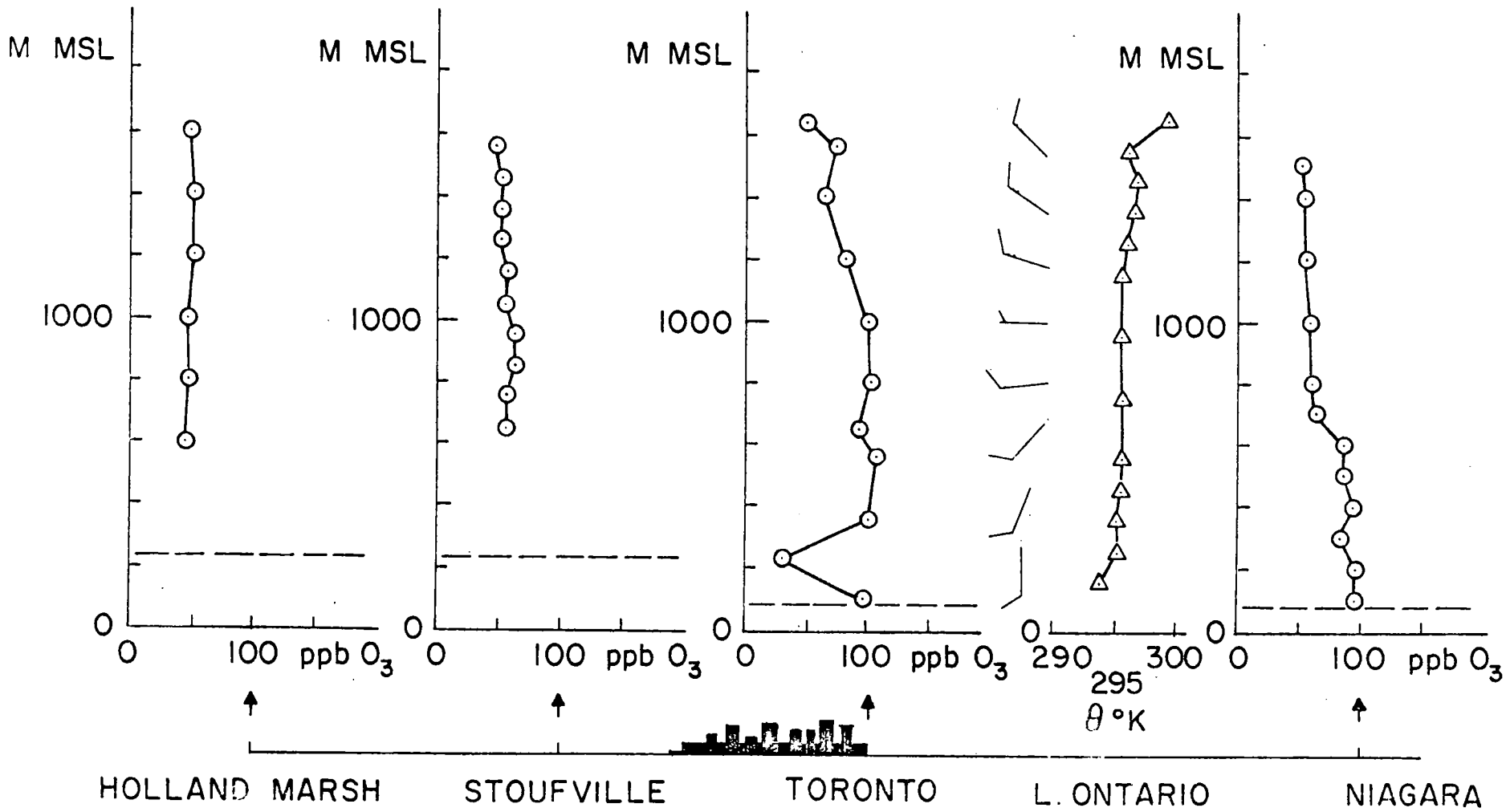

FIGURE 3: Aircraft ozone measurements on August 28th, 13-16 EST.

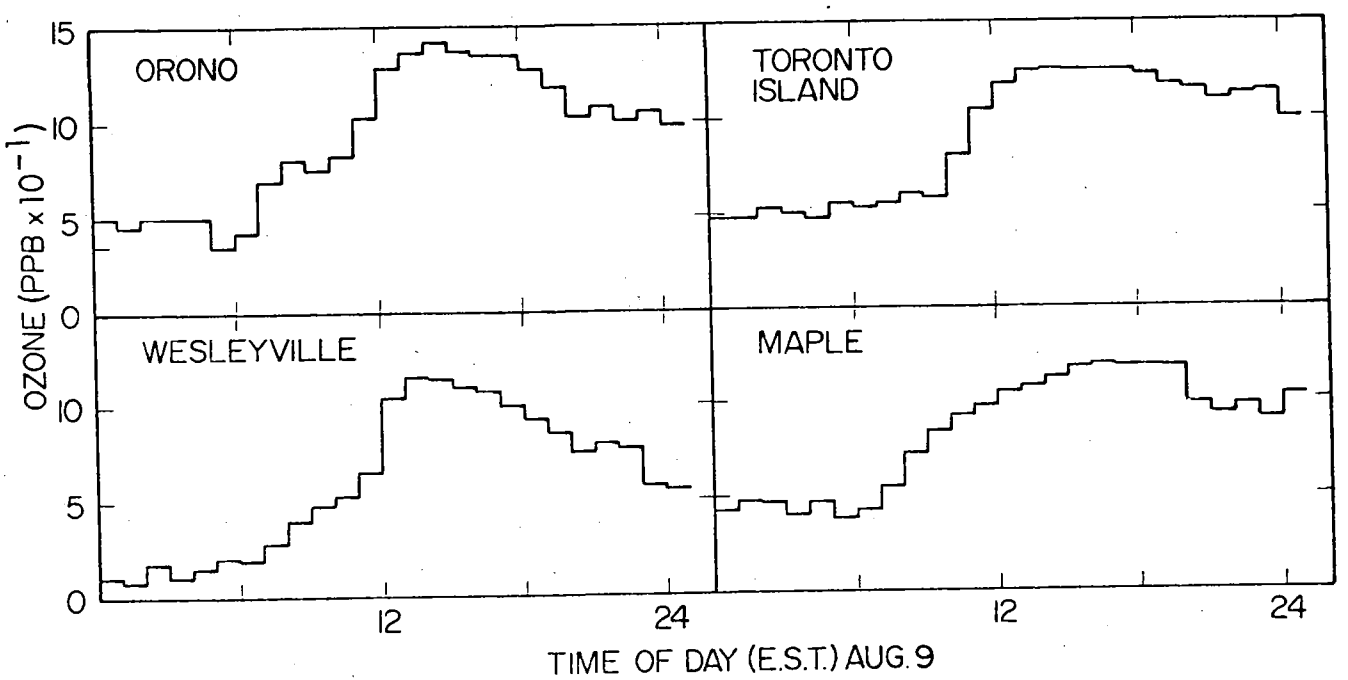

FIGURE 4: Hourly ozone averages at ground level monitoring stations on August 9th, 1975.

network. Several stations in eastern Canada measure daily regional particulate ionic constituents such as sulphate, nitrate, etc. and gaseous sulphur dioxide, as well as acidity and ionic constituents of precipitation. The results will be correlated with air parcel trajectories, calculated from a model of M. Olson (see other workshop articles on modelling).

INORGANICS -- MERCURY IN THE ATMOSPHERE

The atmospheric burden of mercury can be as large as that for the aquatic or terrestrial environment. But it is only recently that the environmental impact of atmospheric mercury has been considered seriously. Major natural sources of atmospheric mercury include volcanic activity, weathering of rocks and degassing of the earth's surface matter. Anthropogenic sources include combustion of fossil fuels, chlor-alkali plants, smelting of ores (such as zinc, copper or lead), mercury production itself (from mining to refining) and incineration or disposal of wastes (such as mercury batteries, lamps, switches etc.) By way of example, for 1970, Environment Canada has calculated that about 82.2 tons of mercury were released into the Canadian atmosphere.

In speaking of mercury in the atmosphere, it should be realized that this pollutant may exist in the gaseous phase in elemental form or as part of chemical compounds such as methyl mercury, mercuric chloride, etc.; it may be part of solid particulate matter as is usually collected on Hi-Vol filters; or it may be scavenged by precipitation. It turns out that the mercury in particulates makes up only a small fraction of total atmospheric mercury content. For example, in Chicago, particulate mercury was measured to be from 2 to 10 ng/m^3 whereas elemental mercury was from 5 to 60 ng/m^3. Background levels of particulate mercury have generally been below 0.06 ng/m^3.

Another interesting finding has been that atmospheric mercury seems to decrease sharply with height; surface concentrations may be 10 to 20 times higher than those at 100-150 m.

During the summer of 1977, ARQA participated in an air-

craft survey of elemental mercury over southern Ontario. Because of limitations in instrumental sensitivity, only a cursory survey was attempted. It was found that concentrations were highly variable, both as a function of altitude and location. Measured atmospheric concentrations of mercury were generally about 1 ng/m^3 with maxima as high as 5 ng/m^3 on some occasions.

In this article, only a few highlights have been presented. So the reader is referred to Dr. Schroeder (ARQA) who completed an extensive literature survey of atmospheric mercury and its measurement (see also reference 3). Presently, work is in progress in our laboratories on the development and evaluation of techniques for measuring elemental mercury and its chemical compounds in the atmosphere.

ORGANICS

The goal is to measure ambient levels of selected organics and to study their dispersion, transport, transformations and removal. The organics under consideration are ones which have proven toxicity, persistence and wide-spread distribution in the atmospheric environment. These include (i) polychlorinated biphenyls (PCB's) -- used as dielectric fluids in transformers and capacitors, (ii) pesticides -- such as chlordane, endrin or parathion, (iii) polynuclear aromatic hydro-carbons -- produced during combustion and other processes, and (iv) dioxins -- found as a contaminant in pesticides or herbicides, or may be produced as a result of combustion of chlorophenols, phenoxy acids, etc. such as at municipal or industrial incinerators. Particular attention must be paid to the removal processes such as wet and dry deposition, the adsorption - desorption mechanisms on atmospheric particulates, or the sensitivity of these organics to photochemically induced transformations. In the latter case, it should be noted that some of the reaction products may be much more toxic than the parent organic molecules. For example, hydroxy substituted polychlorinated biphenyls. are photochemical products of the parent PCB's and are estimated

to be 10 to 100 times more toxic.

Presently, ARQA is engaged in a co-operative research program with the University of Waterloo to develop reliable analytical procedures for collecting and analyzing atmospheric samples of organics whether in vapour or particulate form; the classic method of Hi-Vol filter samples is inadequate because it yields only the organic particulate component.

ATMOSPHERE-BIOSPHERE INTERFACE

Major sinks for atmospheric contaminants are the marine, freshwater and vegetated surfaces. Studies within ARQA have concentrated on the role of vegetation as a sink for atmospheric contaminants. Research has included surveys of the metal content of vegetation, estimates of deposition rates to vegetative surfaces from the atmosphere, and studies on the accumulation, retention and loss of such contaminants by vegetation.

One plant growth form, the lichens, has been studied in detail. The reasons for this choice were twofold. Firstly, the ubiquity of lichens in northern ecosystems and secondly, their ability to accumulate mineral elements to levels far greater than their expected needs. Lichens, unlike other plants, have no roots and therefore are dependent on substances dissolved in precipitation for their nutrients. This feature together with longevity allows for their consideration as long term integrators of atmospheric deposition.

In New Brunswick, studies were made of the deposition patterns of various atmospheric contaminants as reflected in the elemental content of vegetation. Clearly defined deposition patterns of such elements as vanadium, nickel, sulphur, iron, titanium and chronium have been described and the highest concentrations are found in lichens collected within the city limits. The combustion of fossil fuel is believed to result in the enhancement of Ni, V and S concentrations in lichens while automobile exhaust contributes to the lichen lead levels. However differences in the lichen elemental content from year to year only reflect the annual integration. An estimate of depos-

ition over a shorter time period (one month) can be accomplished by the use of moss-bags. This technique consists of a flat, square nylon mesh packet (10x10 cm) containing ∿3 grams of moss. The moss-bag is exposed to the air where it can intercept airborne dust and rainfall, for a fixed period of days, after which it is removed for chemical analysis. Moss-bags were put out at 60 sites around Saint John over the period, September - October, 1978, and presently are being analyzed for their elemental content.

Increasing industrialization of the Canadian North has resulted in concern over the environmental impact of such activities. In order to survey the existing loadings of potential problem substances, lichens were collected from 45 Arctic sites and analyzed for 20 elements. Such data provide not only a baseline for that region but also allow comparison with other areas within Canada. Statistical analyses of this data have shown, in part, the relationships which exist between the elements which are deposited via wet and dry deposition to the lichen surface. In remote areas, such as the Canadian Arctic, the main contribution to the lichen metal burden would seem to be atmospheric particulates derived from the weathering of crustal material.

As stated earlier, lichens are dependent on the processes of wet and dry deposition for their metabolic nutrients. To facilitate the utilization of such nutrients, lichens possess an array of extracellular enzymes. The location of these enzymes makes them highly susceptible to changes in their immediate environment; hence, they can be used as an assay of the effect of various environmental stresses. Enzymes such as the phosphatases are relatively tolerant of contaminants such as Pb, Cu, Ni and Ag but are extremely sensitive to such metals as vanadium and molybdenum. This marked sensitivity to vanadium is very significant with respect to recent changes in air quality. Vanadium levels in atmospheric aerosols have been increasing steadily as the result of increasing fossil fuel combustion. Vanadium levels have been found in particulates and precipitation in certain

localized areas within Canada, with corresponding high vanadium concentrations being found in lichens collected from these areas. Concern is being expressed as to the fate and effect of this metal (see LRTAP program) and indeed some evidence is available to suggest that current atmospheric emissions around localized sources can have a significant effect in reducing certain metabolic processes in vegetation. For further details the reader is referred to references 4 and 5.

AIR QUALITY CRITERIA AND OBJECTIVES

The Atmospheric Environment Service has a dual role to play in the development of air quality criteria and objectives. The first is to carry out research in order to fill gaps in knowledge about effects of air pollutants -- for example, on Arctic ecosystems. The second is to coordinate the collecting and summarizing of technical information already available on the subject of effects of air pollution. An example of this is the draft of a criteria digest on nitrogen dioxide -- only recently prepared by ARQA. For this case study, a computer literature search was made and the relevant data of some 600 publications was abstracted and tabulated. This criteria digest will be reviewed by a number of experts who are currently engaged in research on biological effects of nitrogen dioxide. Then, it will be used by the Federal-Provincial Sub-committee on Air Quality Objectives as the basis for setting a national nitrogen dioxide objective.

WMO BASELINE MONITORING OF CARBON DIOXIDE

ARQA is presently engaged in monitoring background levels of CO_2 at three Canadian baseline (clean) sites: Weather ship PAPA, Alert and Sable Island. The goal is to aid in documenting the global CO_2 concentrations and gradients over a long period of time, Canadian data obtained over the last few years confirms the global increase in CO_2. Figure 5 shows this trend in CO_2 increase as measured at various background stations. The reader may contact K. Pettit (ARQA) for further information.

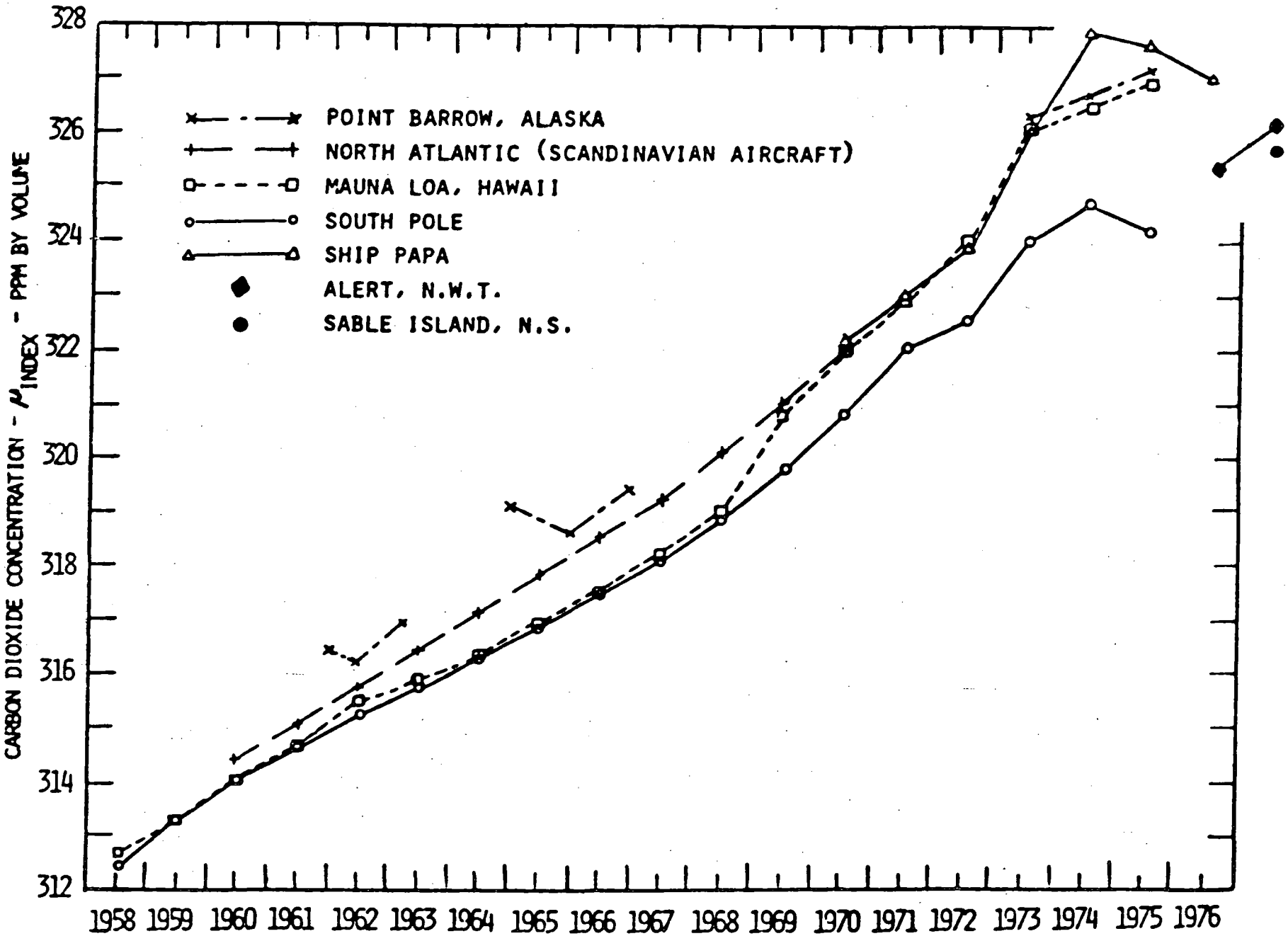

FIGURE 5: Annual CO_2 concentration.

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OBSERVATIONAL SYSTEMS AND TECHNIQUES

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Atmospheric Dispersion Division

INTRODUCTION

Any attempt to describe all the observational systems used by AES for Air Pollution Meteorology would go far beyond the scope of this presentation. The author would refer anyone interested in a more detailed description of the devices used by the Air Quality and Inter-Environmental Research Branch to a set of course notes prepared for the Air Pollution Meteorology Course. This presentation will centre on six devices whose development in the last few years may not be familiar to you and will become of increasing interest, and, we hope, enjoy increasing application by the regions of AES.

There is a rather unimportant dividing line which will appear in the following presentations which will separate meteorological and air quality measurement techniques. The author will follow that precedent in this paper although it should be noted that users within ARQD seldom make distinctions along these lines.

METEOROLOGICAL DEVELOPMENTS

The device most likely to become a standard tool of the regions of AES is the minisonde. The minisonde system consists of a sonde transmitting an FM signal on the 403MHZ meteorological band which carries temperature information from a thermistor. The sonde is attached to a pilot balloon and the ascent is tracked by two observers using theodolites at the end of a baseline of approximately 100 meters. Techniques using constant rise rate calculations for the pibal and a single theodolite have been demonstrated experimentally at AES to be unsatisfactory for adequate accuracy in wind direction and speed. The readings from the dual theodolites are fed into a routine developed by Vickers which using Thyer's method minimizes tracking errors of the balloon and calculates balloon position.

Several developments in the minisonde system are currently underway. AES has purchased five complete FM receiver units from Aeroaqua Ltd. These receivers are currently under evaluation by the Atmospheric Dispersion Division (ARQT). Problems with the low temperature range of the sondes is currently being solved by Instruments Branch and the Atmospheric Dispersion Division. This modification to the sondes should facilitate operation to -50°C.

A problem mentioned by Atlantic Region was that higher vertical resolution is needed for the minisondes. This entails reading theodolites at 15 second rather than 30 second intervals. This can, of course, be done with the present system with significantly more wear and tear on the observers. An alternative being investigated is the use of digital theodolites with either telemetry or fibre optic links to a central desk calculator. In addition, radar balloon tracking has been considered in the past, but the cost of such a system appears to be a limiting factor.

On the data analysis side, routines in the BASIC programming language are available to regions for implementation on HP9830A based computing systems. In addition, conversion to PDP 11 BASIC Language has been carried out by Harold Neumann of the Atmospheric Chemistry Division. Documentation for these routines will be available later this year.

Another system which has gotten increasing use in support of regional projects is the Boundary Layer Research Division (ARQL) tethersonde. A new sonde is being designed by R.E. Mickle and L. Guise-Bagley of ARQL to give increased sensitivity and frequency response for turbulence measurements. In the old sonde several measurement systems and the readout systems were electromechanical. In the new sonde (see Table I) devices employing only electronic principles will be employed.

Construction of components of the new sonde are being contracted out at present and the device (Figure I) will be compared to a tower by the end of May 1979 and ready for service by the end of June.

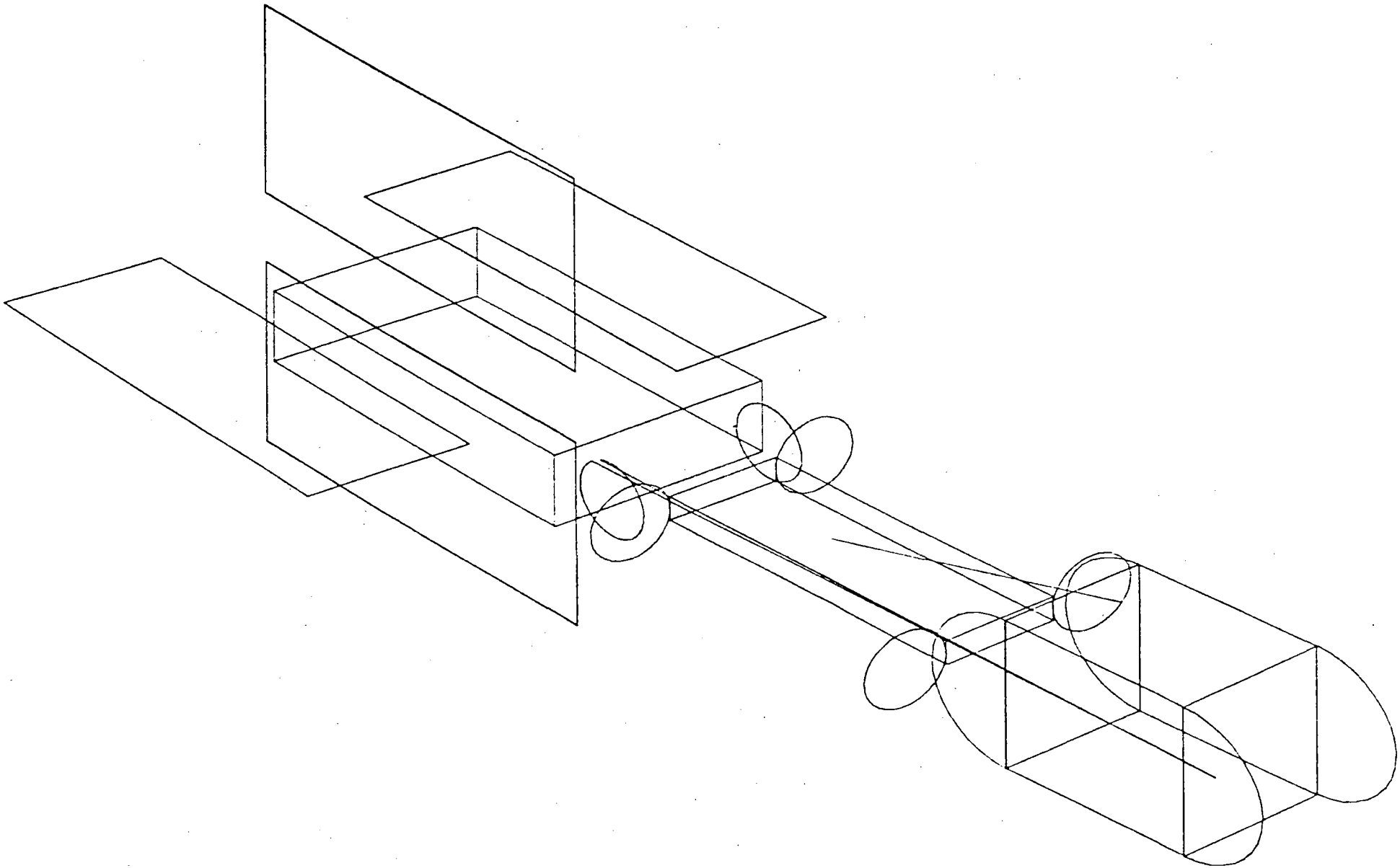

Figure 1 - Computer X-Ray View of
New ARQL Tethersonde

TABLE 1

Tethersonde Comparisons

Parameter	Old System	New System
Scan rate	1 scan/9 sec	10 scans/sec
Pressure reading	once/9 sec	once/scan
Humidity reading	once/9 sec	once/scan
Temperature reading	three/9 sec	once/scan
Wind direction & speed	horizontal	horizontal & vertical
Pressure mechanism	bellows (electro-mechanical)	Rosemont capacitive (0.1 mb accuracy)

A third meteorological system under development at AES is the acoustic sounder or SODAR. The reader may be familiar with commerical SODAR units produced by Aerovironment of the U.S. SODARs operate by emitting a burst of sound at about 1600 Hz vertically into the atmosphere and monitor the time of flight and intensity of the returned sound wave. Since the acoustic wave is scattered by density perturbations in the atmosphere and since these density perturbations are primarily due to temperature gradient fluctuations, the SODAR then is capable of monitoring temperature structure. Thus, its primary use is as a means of detecting thermal inversions aloft. The AES SODAR has greater sensitivity than the commercial unit and has a digital data processing capability. As such it shows great promise for giving a much more detailed picture of the thermal structure of the troposphere.

Four of these SODAR units are being used by B. Kerman of ARQL and two additional units are maintained in AIDE of Atmospheric Instruments Branch under W. Clink's supervision. Arrangement for loan of these units to regional SSU's for short-term projects may be arranged with Dr. Kerman and Mr. Clink.

AIR QUALITY SYSTEMS

The rapid expansion in the number and sensitivity of air quality monitoring devices makes any choice of systems to present here difficult. I will, however, use personal biases to describe three systems which are becoming invaluable for air pollution meteorological studies.

The Barringer Correlation Spectrometer (COSPEC) has been used in every dispersion field project at AES Downsview since 1976 under the supervision of M. Millan. The device is a remote sensor of sulphur dioxide vertical burden; that is, it measures the vertical column content of SO_2 over the instrument in units of ppm meters (or $\mu g/m^2$). The principle used is the absorption of skylight by the ultraviolet absorption bands of SO_2 and the instrument thus is well suited to rapid, remote measurement of plume dispersion from aircraft, boats, or ground-based vehicles (Figure 2). Data from the sensor are recorded on charts or magnetic tape and have been reduced in the past by HP9830A based systems. Development work is being carried out in ARQT at present to extract the data via microprocessor based technology for more rapid data reduction. Data reduction procedures have been documented for the BASIC programming language and is available through a Technical Memorandum. Conversion of the programmes to FORTRAN will be completed this summer and will be subsequently documented.

The second system which has emerged in the last two years, is the AES LIDAR system. The LIDAR (for Light Detection and Ranging) is the visible light analog of radar or sodar. Since the LIDAR uses a pulsed ruby laser as a light source, it is sensitive to variations in atmospheric aerosol content and thus becomes useful for profiling particulate plume dispersion. By firing a scan of several shots at varying elevations, composite plume profiles (see Figure 3) can be constructed and horizontal and vertical dispersion coefficients and plume rise can be computed. From that data, LIDAR used in conjunction with COSPEC measurements and meteorological observations becomes an extremely powerful system for gathering remote information on SO_2 mass

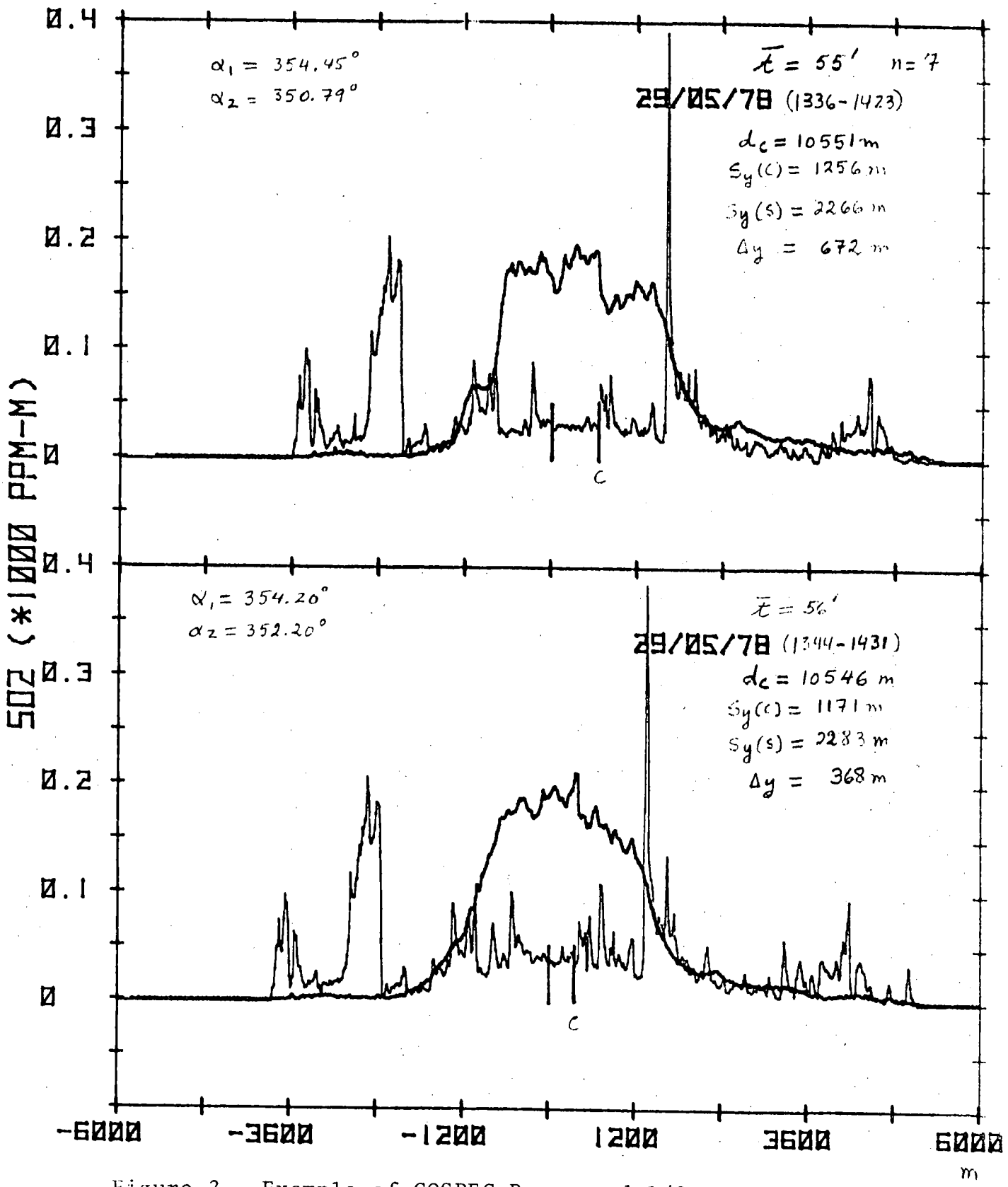

Figure 2 - Example of COSPEC Processed 1/2 Hour Eulerian Averages (Top trace). Bottom trace represents Sign - x SO_2 point monitor output obtained simultaneously (units in ppm).

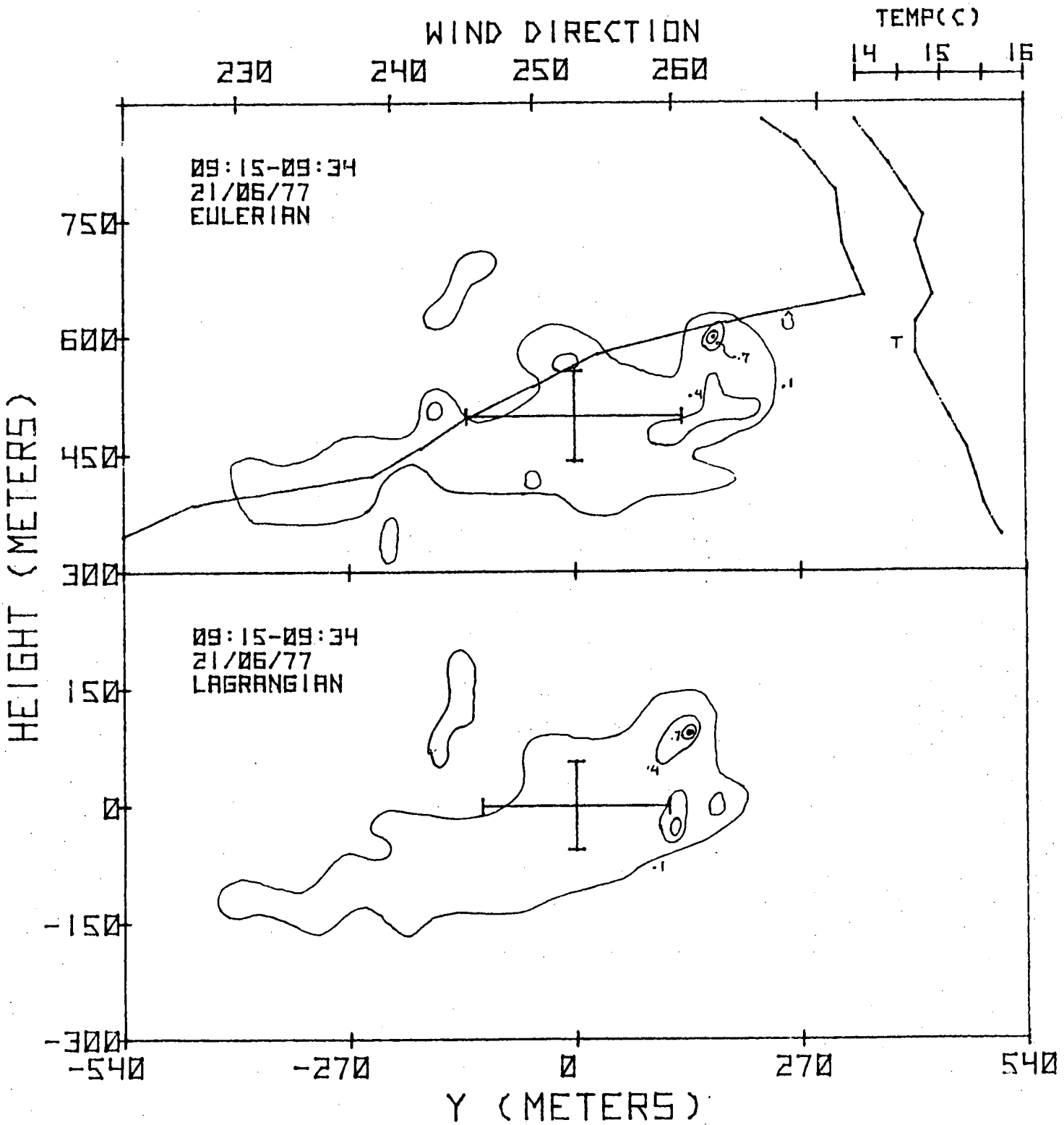

Figure 3 - Example of LIDAR Plume Scans for a Plume Trapped under an Inversion. Cross-hatched lines represent $2\sigma_y$ and $2\sigma_z$ from plume centreline. Û and T are from minisonde release

fluxes from industrial emissions. In addition, work is being carried out towards characterization of the mixed layer of aerosols using LIDAR in a fashion similar to SODAR operation. Results from that work should give useful information on transport of aerosols through inversion layers and the mechanisms involved in haze layer buildups.

A final system which is going to become increasingly apparent to regional personnel is the use of Ion Exchange Chromatography. With the importance of ionic species ion precipitation samples towards an understanding of acid precipitation effects, the use of ion exchange chromatographs, such as the Dionex used by H.A. Wiebe and P. Fellin of ARQA, have become invaluable for detection of sulphates, sulphites, nitrates, nitrites, fluorides and chlorides in precipitation and impregnated filter samples.

Chromatography is a class of techniques where chemical compounds or species are separated from each other on a column which uses a chemical or physical property of the compound. In gas chromatography, the polarity of organic compounds causes differential solubility of these compounds with respect to a tube packed with an organic compound. This differential solubility causes the mixture of compounds studied to travel at different speeds through the column under pressure. From the varied elution times, the mixture of compounds can be separated. In ion exchange chromatography it is the differential affinity of certain ions for specific ionic exchange resins which separates out the ions. The separated eluant is then detected conductimetrically for a signal which identifies the concentration of ionic species in the sample.

This brief paper can only serve as an introduction to AES operational systems and the readers are encouraged to contact Downsview personnel who are responsible for these techniques. To that end Table II provides a resource list of personnel who should be able to answer questions more fully.

TABLE II

Observational Systems Resource List

SYSTEM	CONTACT
Radiation Network Observations	Dr. D. Wardle, ARPX
Minisonde, Delta-T sonde	Dr. H.E. Turner, ARQT
Tethersonde, Turbulence Devices	Dr. R. Mickle, ARQL
Acoustic Sounders	Dr. B. Kerman, ARQL
	Mr. W. Clink, AIDE
Bivane, Plume Photography	Dr. F. Fanaki, ARQT
COSPEC, Sign-x	Dr. F. Fanaki, ARQT
	Dr. R. Hoff, ARQT
Stratospheric systems, SO_2	
HCl Spectroscopic systems	Dr. W. Evans, ARPX
LIDAR	Dr. R. Hoff, ARQT
Chemical monitors (SO_2, NO_x, O_3 etc.)	Drs. H.A. Wiebe and K. Anlauf, ARQA
Hg Monitors	Dr. W. Schroeder, ARQA
Optoacoustic techniques	Dr. H. Sanderson, ARQA
Lichens, Moss bags and other Delicacies	Drs. K. Puckett A. Burton, M. Phillips, ARQA
CANSAP	Mr. R. Berry, ARQT
APN, CAAPP, particulate samplers	Dr. L. Barrie, ARQT
Hydrometeorological systems	Dr. G. Den Hartog, ARQL
	Dr. H. Neumann, ARQA
Organic Sampling	Mr. P. Fellin, ARQA

ARPX - Experimental Studies Division
ARQL - Boundary Layer Research Division
ARQT - Atmospheric Dispersion Division
ARQA - Atmospheric Chemistry, Criteria and Standards Division

DISCUSSION/COMMENT

H.P. SANDERSON: Maybe you can tell us what's the hazard associated with the LIDAR.

R.M. HOFF: There is little hazard physically, unless you are within a few meters of the vehicle as far as being hurt by the beam. Optically, in other words, damage to the eye, it's a significant eye hazard, it depends on the aerosol background, but it's a significant eye hazard for several kilometers from the vehicle, so we've developed some eye safety procedures which involve both looking through that view scope as well as standing outside the vehicle before every shot. Each shot of the laser is done manually; it's not automated, and the man who's running the trigger on the laser has to ascertain there's nothing in the field of view before he fires the shot.

M. MILLAN: Just for the record, the Cospec can also measure nitrogen dioxide.

R.M. HOFF: Yes, that's my fault. I just did (this talk) on a historical basis. Cospecs also could measure nitrous acid, but that hasn't been tested out.

SUDBURY STUDIES

M.M. MILLAN
Atmospheric Dispersion Division*

Abstract: The INCO Tall Stack Plume Dispersion Program will be reviewed. Some of the latest results showing the transport of this plume in the regional scale will also be presented.

(Paper not received)

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* The author is now with Barringer Research Ltd., 304 Carlingview Drive, Weston, Ontario.

THE NANTICOKE STUDY

R.V. PORTELLI
Air Quality Assessment Section

INTRODUCTION

Intensive shoreline diffusion experiments were conducted from May 29 through June 16, 1978 in the Nanticoke area on the north shore of Lake Erie - in the vicinity of Long Point Bay. These field experiments were mounted by the Atmospheric Environment Service (AES) of Environment Canada with cooperation from the Ontario Ministry of the Environment (OME) and Ontario Hydro. This short paper/presentation will provide a brief description of the industrial activity in the area, outline the on-site observational program and give a preliminary overview of the findings.

THE NANTICOKE INDUSTRIAL COMPLEX

The Nanticoke area on the north shore of Lake Erie (see Figure 1) will be a centre of major industrial development in Ontario over the next decade. Initial investments of Ontario Hydro, Stelco and Texaco are in excess of four billion dollars. It has been estimated that by the year 2000, total investment in heavy industry, secondary industry, commercial and residential development will exceed 20 billion dollars. At present, the power plant is operating at a generating capacity of about 2500 MW and the last of eight 500 MW units is currently being commissioned for a maximum capacity of 4000 MW - making it the largest fossil fuel power plant in the world. During 1979 Stelco and Texaco are scheduled to begin production at 1.9 million tons of steel per year and 100,000 barrels of oil per day, respectively. By 2000, Stelco expects to reach 12 million tons per year and Texaco may double production. Without considering potential expansions, there is no doubt that the development is the largest undertaken in Canada - far larger, for example, than the Alberta Oil Sands development.

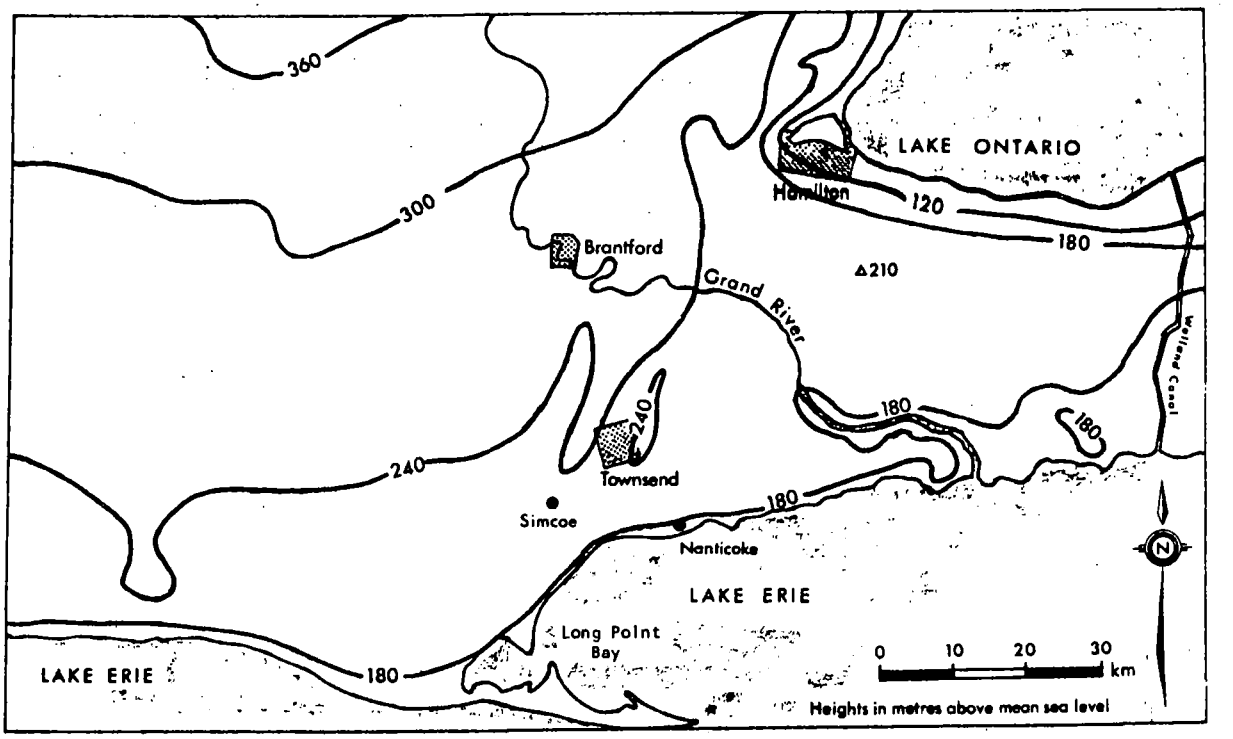

FIGURE 1. LOCATION MAP - NANTICOKE

By 1980 the Nanticoke complex will be a major source of air pollutants (Smithies, 1977). Emission estimates for oxides of nitrogen and oxides of sulphur are 100,000 tons per year (second in Ontario only to those of the Sudbury Inco plant), respectively. The large volume of NO_x emitted may participate in photochemical reactions with hydrocarbons from the Texaco operation and hydrocarbons and particulate matter transported from other industrial centres such as Buffalo, Cleveland, Hamilton, etc. Consequently, it is anticipated that the complex may be a source of oxidants. For further information regarding the Nanticoke complex refer to Cross (1977) and Smithies (1977).

DIFFUSION IN SHORELINE ENVIRONMENTS

When industry is located in shoreline environments, a major consideration, from the point of view of impact on local air quality, is continuous fumigation of coastal plumes. This phenomenon occurs during the spring and summer with onshore flows.

During this period of the year when the air over the land is often 10°C or more warmer than that over the lake, the stable lake air advecting over the land surface becomes quickly modified and a Thermal Internal Boundary Layer (TIBL) is produced (see Fig. 2a). Elevated coastal plumes travel inland with little disperal in the stable flow aloft until they reach the upper edge of the TIBL. At this point (this inland distance is dependent on plume and site characteristics - observations of Dooley (1976) indicated 5 to 15 km), the convective turbulence of the underlying unstable air fumigates the plumes to the ground resulting in high ground level concentrations as shown in Fig. 2b. Unlike morning inversion breakup fumigation which lasts on the order of 30 to 45 minutes, this type of fumigation may persist for many hours. The frequency of occurrence of conditions which could produce a TIBL on the northern shore of Lake Erie has been estimated at 25.4% of the days during the months April to September, inclusive (Weisman and Hirt, 1975). This figure is based on data from 1970 to 1974 and takes into account onshore flows resulting from lake breezes and gradient winds.

Another important consideration is what can occur during offshore flows in the warm season. In such conditions pollutants are transported across the lake in or above a stable layer with very little dilution - diffusion over water is substantially less than that over land (Portelli, 1976). Some kilometers inland on the downwind shore the plume intersects the TIBL and fumigation occurs.

EXPERIMENTAL PROGRAMS

To determine the physical characteristics of boundary layer development with onshore flows during the warm season in this area and to investigate the type of dispersion conditions and chemical interactions that the pollutants in the plumes from the coastal power plant (with two 198 m stacks) would be subjected to, the following on-site measurements were taken:

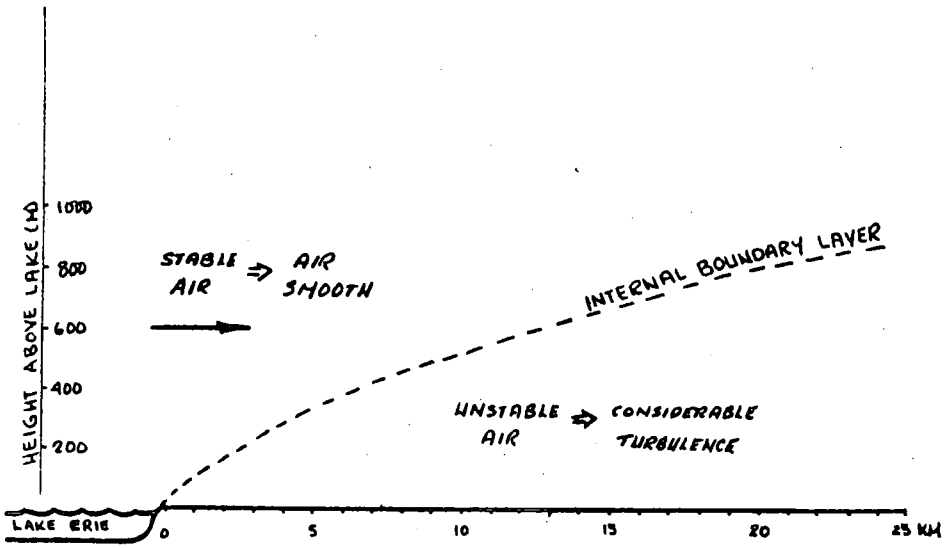

Fig. 2a.

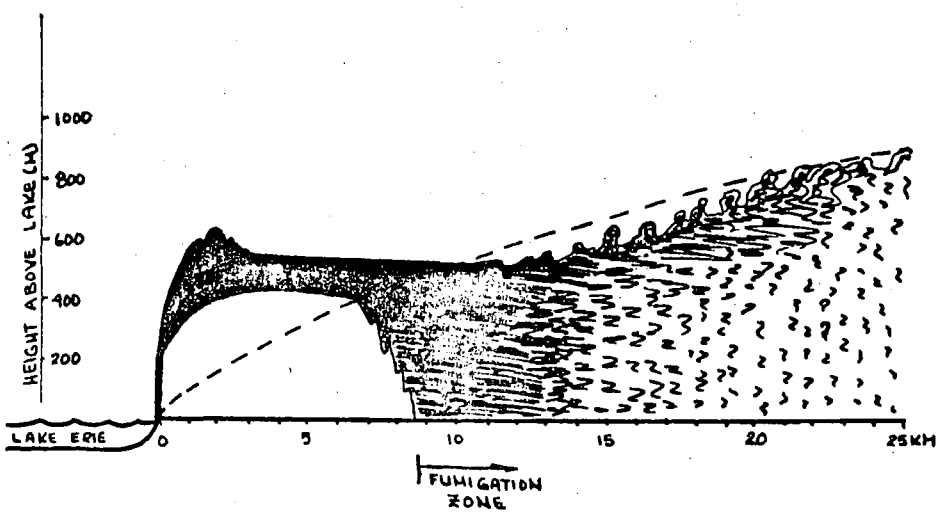

Fig. 2b.

(a) Detailed measurements of wind flow, temperature, relative humidity and turbulence to a level of about 500 m above ground employing two tethersonde systems (TS) - a large tethered balloon transporting an instrument package aloft which telemeters data to a ground receiving station (profiling or fixed-level modes can be used).

(b) Detailed measurements of wind speed and direction and temperature to a level of about 2 km utilizing 3 minisonde

systems (MS) - a free floating pilot balloon, tracked by double theodolites, carries a temperature sensing device which telemeters the data to a ground receiving station; one minisonde system was operated by OME.

(c) Continuous records of thermal turbulence structure in the boundary layer to heights of about 1000 m using 3 acoustic sounders (AS) - one unit operated by OME.

(d) Continuous near surface measurements of sensible and latent heat fluxes and momentum transfer using a sonic anemometer (SF site) and eddy correlation techniques; in addition, measurements of temperature, humidity and SO_2 were made at two levels to determine SO_2 flux near the surface.

(e) Measurement of dispersion coefficients for the power plant plume as a function of downwind distance employing 3 mobile correlation spectrometers (COSPECS), 2 of which were operated with SO_2 SIGN-X monitors; the COSPEC/SIGN-X units (CS) were instrumental in identifying the plume, which was often invisible, its lateral extent, approximate center of mass aloft and ground impingement areas.

(f) Measurements of particulate plume rise and dispersion of the power plant plume as a function of downwind distance using a Light Intensity Detection and Ranging (LIDAR) system.

(g) Measurements of ground-level concentrations of various gaseous (SO_2, NO_x, O_3, hydrocarbons) and particulate (sulphates, nitrates, metals, light scattering, etc.) pollutants, both in identified fumigation areas and further downwind employing two AES laboratories, one fixed the other mobile (CHEM LAB), plus the very sophisticated OME Mobile Air Monitoring Laboratory (MAMA).

(h) Measurements of airborne concentrations of SO_2 by helicopter (KOPTER) to determine the vertical distribution of SO_2 in the plume at locations just downwind of the stack, in the identified fumigation zone and further downwind; this was a joint OME and Ontario Hydro activity supported by AES.

(i) Fixed winged aircraft (Piper Navajo - WQX) measurements of SO_2, O_3, light scattering particles, sulphates, temperature

and relative humidity both upwind (over the lake-background) and downwind of the plant at several altitudes to determine the quality of air masses entering and leaving the Nanticoke area.

(j) Finally, a base station operation (BASE) which was the control center and temporary forecast office where standard surface meteorological observations were made in addition to the observations of wind speed and direction at 3 levels on the 100 m tower at this site-operated by Ontario Hydro. OME and Hydro also cooperated on obtaining continuous measurements of wind fluctuations to acquire turbulence statistics employing a UVW anemometer located on the tower 60 feet above ground.

The locations of the above observational systems are shown in Fig. 3. The minisonde (MS), tethersonde (TS), and acoustic sounder (AS) systems which were deployed inland from the lake along the prevailing wind direction are the key units for observing boundary layer depth. Also, an alternate set of minisonde sites was selected for S-SE flows, denoted by B10, B14 and B20.

The field strategies used can be summarized briefly by the following:

(a) Conditions of primary interest - on-shore flows, particularly those of stable stratification (0630 h briefing on meteorological conditions).

(b) All units operational by 0800 h.

(c) COSPEC/SIGN-X units (CS) traverse at 3 downwind locations to identify plume bearing overhead and any impingement zones.

(d) LIDAR unit positioned to identify plume bearing as well as plume elevation.

(e) Mobile air monitoring laboratories, MAMA and CHEM LAB, positioned in areas of expected impingement.

(f) Flight plans prepared for helicopter (KOPTER) to traverse plume roughly at right angles in the pre-fumigation zone, the fumigation zone, as well as slightly further downwind. Typically the KOPTER flight plan at each specified down-

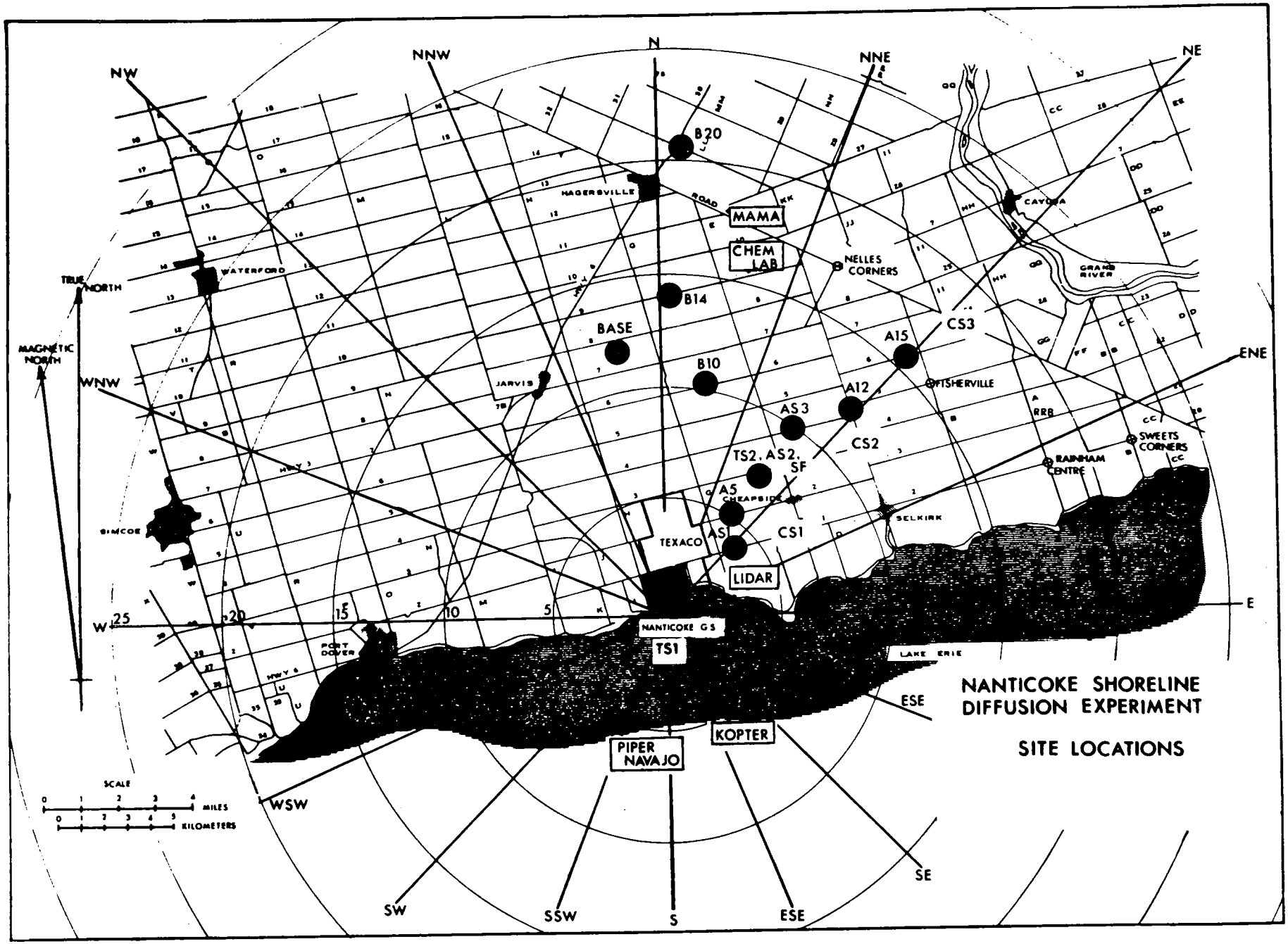
NANTICOKE SHORELINE
DIFFUSION EXPERIMENT
SITE LOCATIONS
N
NNE
NE
ENE
E
ESE
SE
S
SSW
SW
WSW
W
WNW
NW
NNW
TRUE NORTH
MAGNETIC NORTH
B20
MAMA
CHEM LAB
B14
BASE
B10
A15
CS3
A12
AS3
CS2
TS2, AS2, SF
A5
AS
CS1
LIDAR
TS1
KOPTER
PIPER NAVAJO
TEXACO
NANTICOKE GS
HAGERSVILLE
WATERFORD
JARVIS
SIMCOE
PORT DOVER
NELLES CORNERS
FISHERVILLE
CAYUGA
GRAND RIVER
SELKIRK
RAINHAM CENTRE
SWEETS CORNERS
CHEAPSIDE
LAKE ERIE
SCALE
MILES
KILOMETERS

Fig. 3.

wind distance consisted of 5 different elevation cuts repeated 3 times.

(g) Flight plans prepared for Piper Navajo (WQX) also to intersect plume orthogonally but further downwind than the KOPTER in the well mixed zone. Also, background flights were made over Lake Erie. The transecting flight plans at each location were similar to those of the KOPTER. WQX also flew spirals from about 1800 feet msl up.

(h) Observations from MS, TS and AS units re stable or inversion layers aloft as well as wind shear zones were checked with LIDAR plume height observations to assess roughly conditions controlling plume dispersion.

(i) Once impingement/fumigation zone(s) were identified, MAMA, CHEM LAB, KOPTER and WQX were relocated accordingly - CS units also relocated if better coverage possible.

(j) Continuous monitoring of synoptic and local weather was carried out by the on-site forecast unit which provided frequent forecast briefings and updates.

(k) Once plume monitoring during a particular day was underway the above operations were continued until (i) the winds shifted carrying the plume out over water, (ii) the plume decoupled completely from the surface layer - this typically occurred about 1800 to 1900 hrs, or (iii) weather activity (precipitation, storms, etc.) prevented continuation.

RESULTS

During the field study period of May 29 through June 16, 1978 operations were cancelled for June 9, 10 and 11 due to weather and zero weekend load conditions at the power plant. On 8 of the remaining 15 days, the power plant plume was transported inland by gradient/lake breeze on-shore flows - during late spring and early summer, such daytime on-shore flows are expected to occur about 1 day in 3 in the Nanticoke area. The ground-based meteorological and air quality observational systems were essentially 100% operational for the majority of the time and the weather conditions were such that the 8 days were complete data days (i.e., not interrupted or terminated by foul weather). These days are as follows:

May 29, 30; June 1, 4, 6, 12, 15, 16.

Due to aircraft difficulties, airborne sampling coverage was not as complete. The Piper Navajo (WQX) was on-site for all of the above days except for May 29 and 30. The helicopter (KOPTER) sampling unit was available for only June 6, 15 and 16. Additionally on June 1, an AES routine ART (Aerial Radiation Thermometer) flight was done over Lake Erie to obtain lake surface temperatures - the rough data were provided shortly after the flight.

On each of the 8 "data days" ground impingements/fumigations were observed. It appears several of these days are of the classical coastal fumigation type (May 29, 30, June 1 and 16) - that is with stable on-shore flows transporting the plume inland where it interacts with the internal boundary layer and fumigates. The zones of fumigation ranged from close in locations at about 7 km from the plant out to 20 km or more. The fumigation zone was observed to move in or out as a result of boundary layer build up or decay as well as rotating with wind shifts. However, the fumigation zones were most consistently found in the sector from N to NE of the plant.

A sample of boundary layer observations is given in Fig. 4 which depicts the variations in time and space of the boundary layer height during a 7-hour period on June 1, 1978. The power plant plume on this day was generally in the layer from 300 to 450 m (plume rise data by R. Hoff) and fumigation occurred from about 1100 to 1630 h - the maximum hourly average concentration of 363 ppb occurred 16 km NNE of the plant in the 1400 to 1500 h period (Ontario Hydro, 1978).

Also, on June 1 the plume was observed to travel back towards the lake in a return flow aloft which would indicate a complete lake breeze circulation. The maximum air temperatures on this day were about 28°C and the ART flight indicated that surface temperatures ranged from about 12 to 18°C - the warmer surface waters were banked on the southern shore of the lake as a result of strong NW flow on the previous day.

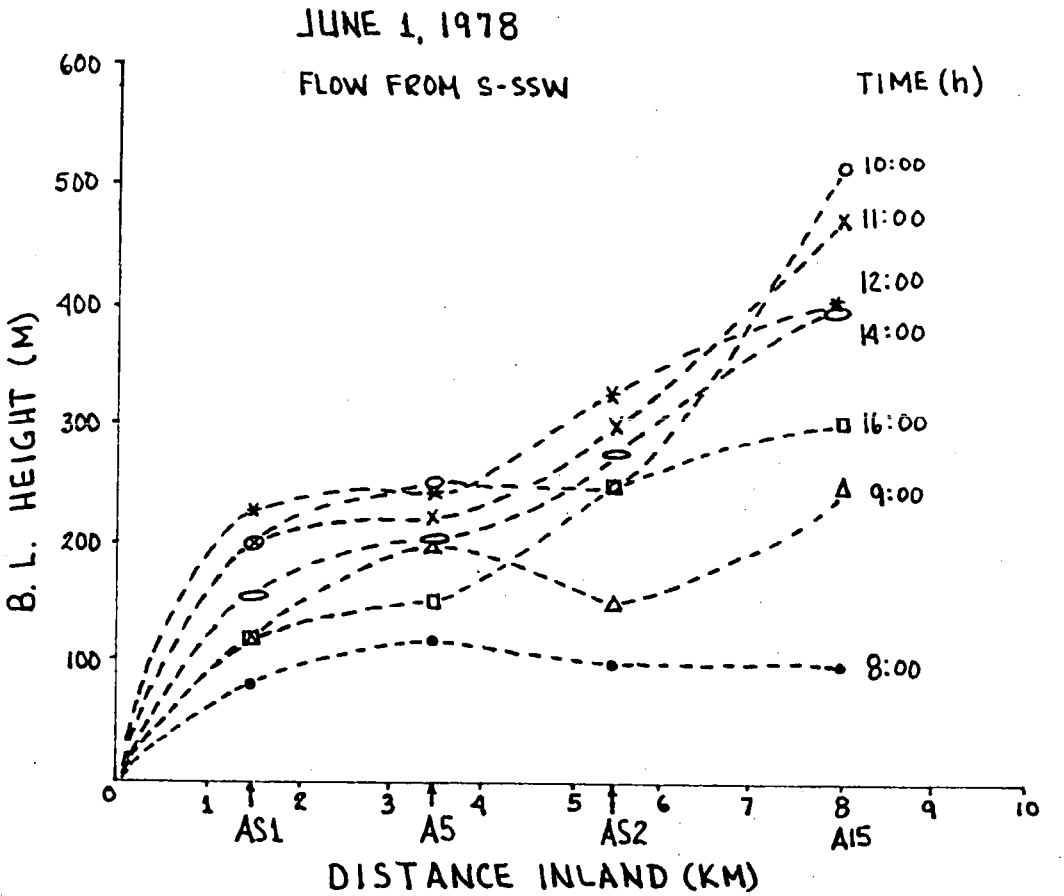

Fig. 4. Boundary Layer Profiles (acoustic sounder (AS) data by B.R. Kerman).

Except for the beginning and end of the study period which caught the end and beginning, respectively of warm air sectors, the remaining period was dominated by relatively cold air. Consequently, air travelling over the lake from the south during the day had temperatures lower than those of the lake surface resulting in roughly neutral on-shore flows. With the existence of shallow stable layers at about 200 to 300 m - probably the remanents of nocturnal inversions aloft being advected across the lake - interesting situations developed on June 4, 6 and 12 as the plume travelled inland and daytime heating increased. The plume appeared to travel inland in or above the stable layer until a point in space and time (about 10-15 km inland and 1100-1300 hrs, respectively) where and when the stable layer was completely eroded from below and the plume

was mixed to the ground.

Another interesting aspect of the plume behaviour is that although the plume is generally invisible - the electrostatic precipitators have an efficiency rating of about 99.5% - a 'brown plume' is evident when the emissions are imbedded in a stable flow. This is attributed to the NO_x in the plume and possibly to the resulting interaction with background constituents. On June 16 such a brown plume was particularly distinct travelling roughly due north to an area about 20 km away from the plant where a clearly visible fumigation was occurring. On this day which was totally overcast it appeared that the boundary layer developed to its maximum extent by about 1100 hrs and stabilized. With the plume bearing and height remaining essentially constant through to about 1600 to 1700 hrs, the fumigation zone remained almost fixed in space for the entire period of time.

In summary, the field investigation was very successful and a comprehensive and valuable data set on shoreline diffusion has been acquired with good observations of coastal fumigation on a number of days. Detailed analysis of the data is nearly complete and a comprehensive report on the experimental program and results will be available soon.

ACKNOWLEDGMENTS

The cooperation of the Ontario Ministry of the Environment and Ontario Hydro is gratefully acknowledged. Also, this study represents the efforts and cooperation of more than 40 scientific and technical staff from AES and the above agencies who made possible the successful execution of the field investigation.

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DISCUSSION/COMMENTS

L.A. BARRIE: Who did the environmental impact assessment for the Nanticoke Power Plant, and how did they do it?

R.V. PORTELLI: It was done by Ted Munn. In 1969 they initiated a rather large Haldeman-Norfolk study on the entire area, and it was really a comprehensive one in terms of geography, surface characteristics, micro-climatology. Ted Munn and Bruce Findlay were involved in doing the preliminary micromet analysis, and they recommended regions along the north shore of Lake Erie where not to locate the plant; like the Grand River Valley just to the east where you would have penetration of lake breezes much further inland, and you would have cold pools of air, and more pronounced problems, but they were restricted to that zone of the north shore of Lake Erie. The actual impact study in terms of air quality was not really done. A subsequent study was initiated by the IJC, which Ted Munn prepared, in response to U.S. concerns. Ted put this together, and he's got a few papers on the transboundary flow. He made simplistic estimates of plume rise, transport and fumigation

(using Turner's workbook methods); actually it was out of the bounds of some of the short-range modelling capabilities, because it was in excess of 100 kilometers (to Buffalo), but he assumed that if the plume is travelling in stable flow over the lake, that there shouldn't be terribly great deviation. One of the other things he did, he used the mixing height statistics that were described earlier, to determine the frequencies of occurrence of various mixing heights and wind direction. On the basis of this study and studies done by the U.S. using the CRSTER model, it was determined that the impact from Nanticoke would be minimal. This is primarily due to the fact that it was the assessment of impact on Buffalo, which does not have very clean air to begin with and they don't have very high standards. However, they're considering upgrading their standards, so if and when they do, that's when Nanticoke may possibly be raised again by U.S. concerns.

ALASKA HIGHWAY GAS PIPELINE STUDY

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BACKGROUND

In the late sixties, the discovery of oil and natural gas at Prudhoe Bay, Alaska and natural gas in the Mackenzie Delta initiated the search for an economic and acceptable means for delivering these hydrocarbon reserves to southern market areas. In 1977, the Alaska pipeline, developed to transport Alaskan oil from the Prudhoe Bay region to the port of Valdez was put into service. From Valdez the oil was shipped by tanker to the U.S. Mainland.

Several proposals were advanced (Figure 1) for transporting the natural gas. The original proposal in 1969 (Arctic Gas proposal) was for a pipeline that would carry both U.S. and Canadian gas from Prudhoe Bay across the North Slope to the Mackenzie Delta, and south along the Mackenzie River Valley to Southern Alberta. At extensive public hearings before the National Energy Board and the Mackenzie Valley Pipeline Inquiry, it became apparent that environmental, technical and socio-economic concerns associated with the proposed location could not be resolved. In May, 1976, the Foothills group proposed the Alaska Highway Pipeline Project. The Foothills proposal called for the pipeline to run south alongside the Alaska oil pipeline to Fairbanks, Alaska, turning southeast to parallel the Alaska Highway past Whitehorse, Y.T. into the north easterly part of British Columbia. From there it would snake into Alberta to connect at James River with separate lines that would carry gas to the U.S. west coast and the U.S. midwest via Saskatchewan. Future plans called for a spur line from Dawson City to the Mackenzie Delta, along the route of the Dempster Highway, to transport Canadian gas to southern markets. In August, 1976, Foothills Pipe Lines (Yukon) Ltd., applied to the National Energy Board to construct a pipeline with a maximum

diameter of 56" which would be buried along the proposed route in the Yukon territories. The Board studied the route and the proposed Mackenzie Valley Pipeline routes and issued its report in July, 1977. In that report, the Board rejected the proposal by the Canadian Arctic Gas consortium and approved the proposal by the Foothills Group. Coupled with the May, 1977 recommendation by Justice Berger against the Mackenzie route, the Alaska/Yukon route became the most accepted means for gas transport.

ENVIRONMENTAL ASSESSMENT AND RECOMMENDATIONS

Where major projects are deemed as having possible environmental impacts, the minister refers the project to the Federal Environmental Assessment Review Process (EARP). The normal procedure for the environmental impact assessment (EIA) is the establishment of an Environmental Assessment Panel (EAP) which issues formal guidelines for the preparation of an environmental impact statement (EIS) prepared by the originator of the project.

In late July, 1977, such a report was issued on The Alaska Highway Project in which several areas were identified for consideration in the EIS report. In particular, it was found that insufficient information was available to predict the information and extent of ice-fog to be expected near compressor stations and in conjunction with this the air quality during winter stable conditions.

PROPOSED COMPRESSOR SITES

Initially five compressor stations (figure 2) were proposed for that section of the pipeline which passes through the Yukon Territories with construction stated to begin in the summer of 1982. As the quantity of gas increases, this will be increased to nine stations. The line is designed for an initial throughput of 1.6 billion cubic feet per day and a maximum throughput of 3.4 billion cubic feet per day which would deliver about 5 per cent of U.S. natural gas needs over 25 years.

Compressor stations will be self contained, fully automated and capable of being controlled from a centre in Whitehorse. Each station in the initial phase will consist of a single gas turbine powered compressor unit and a separate gas turbine power electrical generator using line gas as fuel. Proposed stack and emission parameters for the electrical generator and compressor units are given in Tables 1 and 2. Table 3 presents comparable data for water vapour emissions. It is worth noting that the emission rate for water vapour is in excess of 6000 gallons per hour or about 16% of the estimated total moisture output of the City of Fairbanks, Alaska in 1969.

Three meteorological stations operated by Environment Canada, are relatively close to the proposed pipeline route. These stations (Snag, Whitehorse, and Watson Lake) have records of hourly temperatures for the past 14 to 25 years. However, of these three only Whitehorse has upper air facilities. Only one compressor site (FY-5) will be located in the vicinity of Whitehorse while two other sites (Beaver Creek and Burwash Landing) will be located in the northerly aligned Shakwak Valley. Suspecting that the valley meteorology was site specific, the AES conducted two field trips to these latter sites in Nov./Dec. of 1977/78. These studies were aimed at providing the background information in order that case studies on limited dispersion at the sites could be made. The experiments consisted of two teams conducting simultaneous mini-sonde, tethersonde and acoustic sounder measurements at the two sites for a ten day period. Surface temperatures ranged between -20°C and -50°C during the experimental periods. Under clear skies profiles (figure 3) indicated strong consistent surface inversions (strongest observed 22°C/500m) coupled with light winds. Complex multi-layering within the boundary layer was often observed. These data were presented to Foothills upon completion of analysis so that a limited dispersion analysis could be undertaken.

TABLE 1

PROPOSED STACK AND EMISSION PARAMETERS
FOR THE ELECTRICAL GENERATION UNIT

AMBIENT TEMPERATURE	$25^{o}C$
ATMOSPHERIC PRESSURE	101.325 KPA
TOTAL EXHAUST FLOW	5.74 M^3/s (S.T.P.)*
NOx EMISSIONS (59 PPM)	$3.39 \times 10^{-4} M^3/s$ (S.T.P.)
EXHAUST TEMPERATURE	$460^{o}C$
EXHAUST VELOCITY	75.6 m/s
STACK HEIGHT	7.6 m
STACK DIAMETER	0.49 m

* S.T.P. at standard temperature ($20^{o}C$) and pressure (101.325 KPA)

TABLE 2

PROPOSED STACK AND EMISSION PARAMETERS
FOR THE MAIN COMPRESSOR UNIT (1)

AMBIENT TEMPERATURE (^{o}C)	-23	+15	+25
ATMOSPHERIC PRESSURE (KPA)	101.325	101.325	101.325
RELATIVE HUMIDITY (%)	60	60	60
TOTAL EXHAUST FLOW (M^3/s)	198.7	182.2	174.2
EXHAUST TEMPERATURE (^{o}C)	398	454	462
EXHAUST VELOCITY (m/s)	23.96	21.96	21.00
STACK HEIGHT (m)	13.7	13.7	13.7
STACK DIAMETER (m)	3.25	3.25	3.25
NOx EMISSIONS (m^3/s)	0.0235	0.0253	0.0225
SOx as SO_2 EMISSIONS (2) (m^3/s)	0.0262	0.0251	0.0239

(1) Based on Rolls Royce Cob 6256 (RB211-24)

(2) Emission rates are based on 1% sulphur in fuel. Actual sulphur content of gas is specified at a maximum of 20 grains/100 ft^3. Thus, maximum SOx emissions will be 1/17th of those indicated above.

TABLE 3

PRIMARY COMPRESSOR STATION EMISSIONS

	COMPRESSOR TURNBINES	ELECTRICAL GENERATION TURBINES
AMBIENT TEMPERATURE (T_a)	-40°C (233°K)	25°C (298°K)
EXHAUST TEMPERATURE (T_s)	380°C (653°K)	460°C (733°K)
ATMOSPHERIC PRESSURE	1 atmosphere	1 atmosphere
RELATIVE HUMIDITY	60%	
EXHAUST FLOW (Q_{total})	206 m^3/sec (380°C)	14.4 m^3/sec (460°C)
WATER VAPOUR (Q_{H_2O})	20.6 m^3/sec (380°C)	1.44 m^3/sec (460°C)
	= 6.92 kg/sec	= .431 kg/sec
STACK EXIT VELOCITY (w)	24.4 m/sec	75.6 m/sec
STACK DIAMETER (2r)	3.25 m	.49 m
STACK HEIGHT (h_s)	13.7 m	7.6 m

ENVIRONMENTAL ASSESSMENT

In January, 1979, Foothills Pipe Lines produced an EIS for the Alaska Highway Gas Pipeline Project. It was an extensive examination of the impact of the pipeline on hydrology, vegetation, wild life, terrain and humans within a social and economic setting. A quantitative evaluation of worst case effects due to the compressor emissions was presented as a part of the statement. Applying a dispersion model developed by EPS, Alberta Environment based on trapping due to an elevated inversion and with topographical information being included, maximum ground level concentrations for winds from 1 m/s to 20 m/s were calculated. Maximum hourly ground level concentrations of nitrogen oxides (Table 4) were predicted to be 0.014 ppm or about one order of magnitude less than Federal maximum acceptable objectives. Similar analysis for SO_2 (Table 5) predicted maximum levels of less than 0.015 ppm or an order of magnitude below maximum desirable levels.

However, of more concern was the possible formation of ice fog which would interrupt ground transportation along the Alaska Highway. At compressor stations, the combustion of natural gas in the compressor burbine result in a maximum 10% by volume

of the gaseous discharges being water vapour. Occurrence of dense fog is unlikely except in cases where surface air temperatures are below -35°F and winds are very light. Fourteen years of hourly surface temperature at Snag (Figure 4) for December/January indicate that at least 10% of the time, temperatures are less than -40°F for durations greater than 5 hours, indeed 15% of the time surface temperatures are -40°F or colder.

TABLE 4

MAXIMUM HOURLY GROUND LEVEL CONCENTRATIONS OF NITROGEN OXIDES UNDER WORST CASE METEOROLOGICAL CONDITIONS

AMBIENT TEMPERATURE	GROUND LEVEL CONCENTRATIONS (PPM)		
	DUE TO COMPRESSOR	DUE TO ELECTRICAL GENERATION	DUE TO COMBINED EMISSIONS
-23°C	0.013	0.001	.014
+15°C	0.017	0.002	.019
+25°C	0.017	0.002	.019

TABLE 5

MAXIMUM HOURLY GROUND LEVEL CONCENTRATIONS OF SULPHUR DIOXIDE UNDER WORST CASE METEOROLOGICAL CONDITIONS

AMBIENT TEMPERATURE	GROUND LEVEL CONCENTRATIONS (PPM) DUE TO COMPRESSOR OPERATION	
	1% SULPHUR IN FUEL	20 GRAINS PER 100 CUBIC FEET
-23°C	0.015	< 0.001
+15°C	0.017	0.001
+25°C	0.018	0.001

Surface winds at Beaver Creek (Figure 5) indicate a dominant valley flow during these months with a high percentage of calm conditions and a low-monthly mean wind. Based on these data and the results of the field studies, under worse-case calm stable conditions, ice fog was predicted to radiate to 7 km from the compressor site with visibility limited to 11 m in the thickest areas. However, due to the venting velocities of the water vapour, low settling velocities and the occurrence of sustained calm/low temperature surface conditions, it was concluded that reduced visibility over short stretches of the Alaska Highway near compressor stations would occur only infrequently.

PRESENT STATUS OF EARP

With the environmental impact assessment having been submitted to the environmental assessment panel, a technical review of the statement will be made by government departments and/or others with special expertise in the area of the project. Public hearings are usually held some time after the EIS is issued. These provide opportunities to receive the opinions of all interested persons on the probable impact of the project, to identify and discuss the public's main concern and to discuss the project impacts with all interested parties in technical and non-technical terms. The panel then reviews all information placed before it and makes its recommendations to the Minister of the Environment who with the Minister of the initiating department make the final decision on the proposal.

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DISCUSSION/COMMENTS

S. NIKLEVA: I wouldn't like Bob to leave you with the impression that that's all the use was made out of the data. In actual fact, there was another report put out, and that piece of paper that he produced there on the top it has: "Slaney in Preparation". We actually didn't get that report until part way through the review, but there was a report prepared by Slaney. The second point that we should look at, too, is that this kind of information is really the kind of baseline data we need to review the EIS rather than to do a study, so all we want is something to look at what they've done and say is it acceptable, or do they need more data? I think it did do that. Also with the stronger winds it was quite interesting just to comment on Bob's last remark. We did find that in the valley there, there was a jet at about 200 meters above the ground, and if you use that sort of wind structure with the model of Csanady's that they proposed, you get the base of the plume only at about 27 meters above the ground, so it looks like this would be the general case, so you're going to get ice fog at least very close to ground, even under their conditions, rather than as they suggested, no possibility at all. So the studies were actually very helpful in assessing the EIS.

SPRUCE BUDWORM STUDY

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INTRODUCTION

Inspite of the title of this workshop, the Spruce Budworm Study has not been primarily concerned with either air pollution meteorology or environmental assessment. The study developed from the interests of the Biometeorological Research Section which was left homeless after the dissolution of the Environmental Research Branch in 1974 and which was then appended to the Air Quality and Inter-Environmental Research Branch (ARQB). More recently, in April of this year, the Biometeorology Research Section along with overall responsibility for the Spruce Budworm Study was transferred to the Canada Climate Centre. The study has been included in this workshop because of its previous association with ARQB and my continuing role in it, and because some of its findings are likely of interest to air pollution meteorologists in New Brunswick and other maritime regions.

2. SPRUCE BUDWORM MOTH DISPERSAL PROJECT

The AES study began on a relatively small scale in 1973 in support of a comprehensive program to investigate spruce budworm moth dispersal in New Brunswick that was launched by the Maritimes Forest Research Centre (MFRC), Canadian Forestry Service. The key element of the MFRC program was a ground-based radar used

to monitor the flight activity of the spruce budmoths which occurred primarily in the late evening just after dark. It allowed detection of individual moths above the tree canopy out to 1 km and concentrations of moths to several tens of kilometers (Schaefer, 1976). Special weather forecasts were provided by the Atlantic Region during the study period from late June to mid July while wind and temperature profiles of the lower 1 or 2 km were collected by the Biometeorology Research Section. The wind and temperature profiles proved extremely useful in explaining observed patterns of budworm moth flight and so AES continued to provide these profiles in support of the radar during subsequent years of the Spruce Budworm Dispersal Study from 1974 to 1976 using a combination of ARQB and Atlantic Region Resources.

The interest in spruce budworm moth dispersal stemmed from studies 1970 to 1972 by MFRC during which visual observations from tree-top platforms detected appreciable numbers of moths escaping from the forest canopy at dusk coinciding with large numbers of moths striking the wind screen of a helicopter flying 150 to 300 M above ground, before darkness prevented further observation (Greenbank et al, 1979). Previously, based on early work by Greenbank (1957), active adult migration was not thought to play an important role in dispersing spruce budworm although passive transport associated with thunderstorm updrafts was considered to occur on occasion (Henson, 1951). However the tree-top platform observations and then the radar studies forced re-evaluation of this view.

Radar observations (Greenbank et al, 1979) established that large scale migration of spruce budworm moths occurred nightly in New Brunswick while the moths were active provided that temperatures at take-off time were above a threshold of 17 to 19C. Takeoffs began just before sunset and reached a peak just after nightfall, about 2200 ADT. When radar observations were correlated with wind and temperature profiles, a typical pattern was soon apparent. Moths climbed steeply out of the canopy and congregated in the warmer air at the top of the nocturnal inversion a few hundred meters above ground where they flew downwind with an air speed near 2 m/s so that essentially a layer of moths moving slightly faster than the wind formed over budworm-infested forest. Averaged flight time was about ½ to 1 h , but on a few warm nights flights of 6 h or more were recorded and it appears that flight duration is dependent on how long temperature at flight level remain above the threshold value.

3. OCCURRENCE OF CONCENTRATED LINES OF MOTHS

While a relatively uniform horizontal layer of migrating spruce budworm moths was the common pattern, this was interrupted at least once in each of the study seasons by the appearance of a concentrated band of moths which moved across the radar field-of-view at about 20 km/h. These appearances are summarized in Figure 1. The numbered lines correspond to observed lines in the period 1974 to 1976 and are aligned in the same direction as the observed lines. The direction of movement is indicated by the short arrows joined to the lines. No significance should be

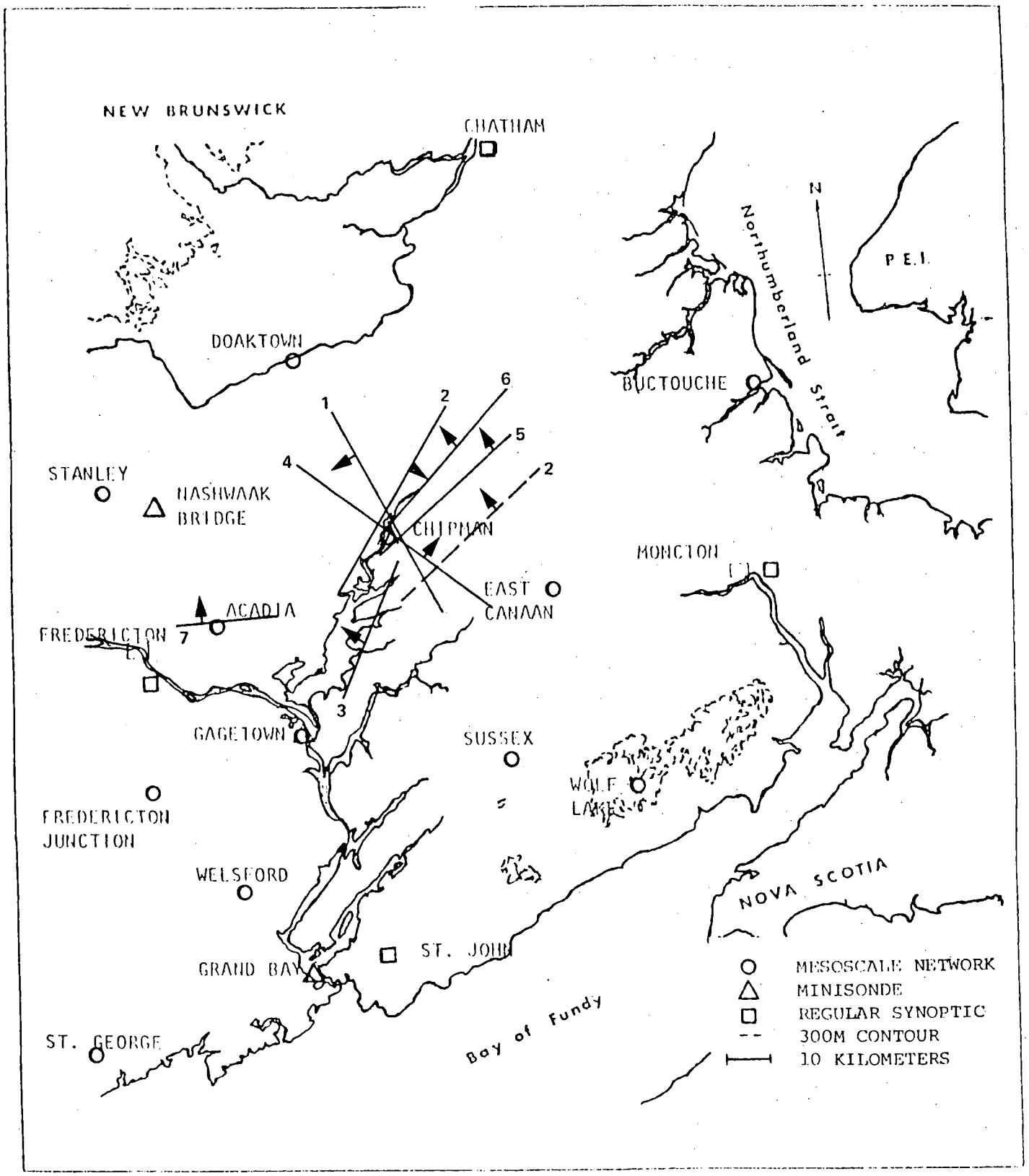

FIGURE 1. LINES OF SPRUCE BUDWORM MOTHS OBSERVED ON RADAR

(1) 10 JUL 74
(2) 12 JUL 74
(3) 16 JUL 74
(4) 17 JUL 74
(5) 8 JUL 75
(6) 10 JUL 75
(7) 10 JUL 76

attached to the exact position or length of these lines in Figure 1. In 1974 and 1975 the insect bands were observed crossing the radar located at Chipman, while in 1976 an insect band was observed at Acadia where the radar had been relocated for that year. With two exceptions, July 10, 1975 and the solid line for July 12, 1974, the lines could not be directly related to synoptic-scale meteorological features.

The July 12, 1974 is particularly unusual. The insect band, corresponding to the dashed line 2 in Figure 1 was detected first moving north eastward. A little later, the second, somewhat more intense line appeared from the northwest and eventually both lines moved off to the southeast. Such insect lines indicate the presence of low level convergence (Schaefer, 1976). Insects which are drawn together by the confluent flow become concentrated in the updraft region at the convergence front as declining temperatures limit their continued ascent. Thus the majority of the lines in Figure 1 reflect the occurrence of mesoscale convergence lines.

Entomologists at MFRC expressed concern about the effects on concentrated bands of moths of spruce budworm on population dynamics and redistribution and possible effects on control strategies based on attacking adult moths (Anon. 1976). Consequently in 1976, AES was asked to expand its role in the spruce budworm dispersal study to investigate the occurrence of these mesoscale convergence lines.

4. ROLE OF SEA BREEZES

Inspection of the alignment and movement of the lines as

shown in Figure 1, showed that lines are roughly parallel to and moving away from one of the two principal coast lines of New Brunswick. This suggested that perhaps the lines arise from seabreeze fronts, although the time of occurrence in the late evening and the distance inland of about 100 km seemed unusual. A preliminary literature review for the study (Kurtz and Hirt, 1976) did not find much support for the seabreeze frontal penetration inland to this extent in temperate latitudes, particularly in the North American literature. However, subsequent digging into the British literature has uncovered a number quite similar to seabreeze events in England (Simpson, 1964; Fergusson, 1971; Smith, 1974; Simpson et al., 1977; Simpson, 1978).

With extensive coast line along the Bay of Fundy to the south and the Gulf of St. Lawrence and Northumberland Strait to the east, seabreezes should be common in New Brunswick from late June to mid July considering that average sea surface temperatures (Everson and Brissett, 1970) are 10°C below average daily maximum temperature inland in New Brunswick during this period. A series of ridges along the south coast may restrict seabreeze movement inland, particularly east of St. John, but an appreciable gap is provided by the St. John River valley. No such impediment is found for seabreezes from the Northumberland Strait. To detect the penetration of seabreeze fronts into the southern half of New Brunswick the four synoptic stations in this area were augmented by a special meso network of surface stations during June and July beginning in 1976. This network was installed with the

co-operations of AES Atlantic Region who have maintained the network in subsequent years. In Figure 2, stations which have provided wind data since 1976 are shown. In 1976 additional stations were located at Cap Pele, Salisbury, Coles Island, Minto and Hampton so that collection was concentrated in two corridors, one eastward from Chipman and one southward. These latter stations were relocated to St. George, Wolf Lake, Sussex, Stanley and Doaktown in 1977 and 1978 to give broader geographic coverage. Around the period of peak moth activity in late June to mid July upper air observations using minisondes were also made. In 1976 minisonde observations were collected at Acadia, co-located with the entomological radar unit and by a mobile unit which alternated daily from near St. John to near Moncton. In 1977 and 1978 minisondes were released at Nashwaak Bridge, Chipman and Grand Bay and also in 1978 at Bass River about 30 km west of Buctouche.

Analysis of results has confirmed that seabreezes are a potential source for evening convergence in south central New Brunswick. Seabreeze frontal passages during daylight were well-marked by abrupt changes in surface wind, temperature and humidity as illustrated in Figure 3 for a seabreeze frontal passage at Gagetown, N.B. on July 10, 1976 at 1810 AST. Note the wind shift from west to east southeast, a temperature drop of 2°C and a relative humidity increase of 15 to 20%. The discontinuity associated with the seabreeze front showed progressive movement inland following its detection near the coast before midday and the chronology for the July 10th event is summarized in Table 1. In this instance surface data indicated a seabreeze frontal passage at

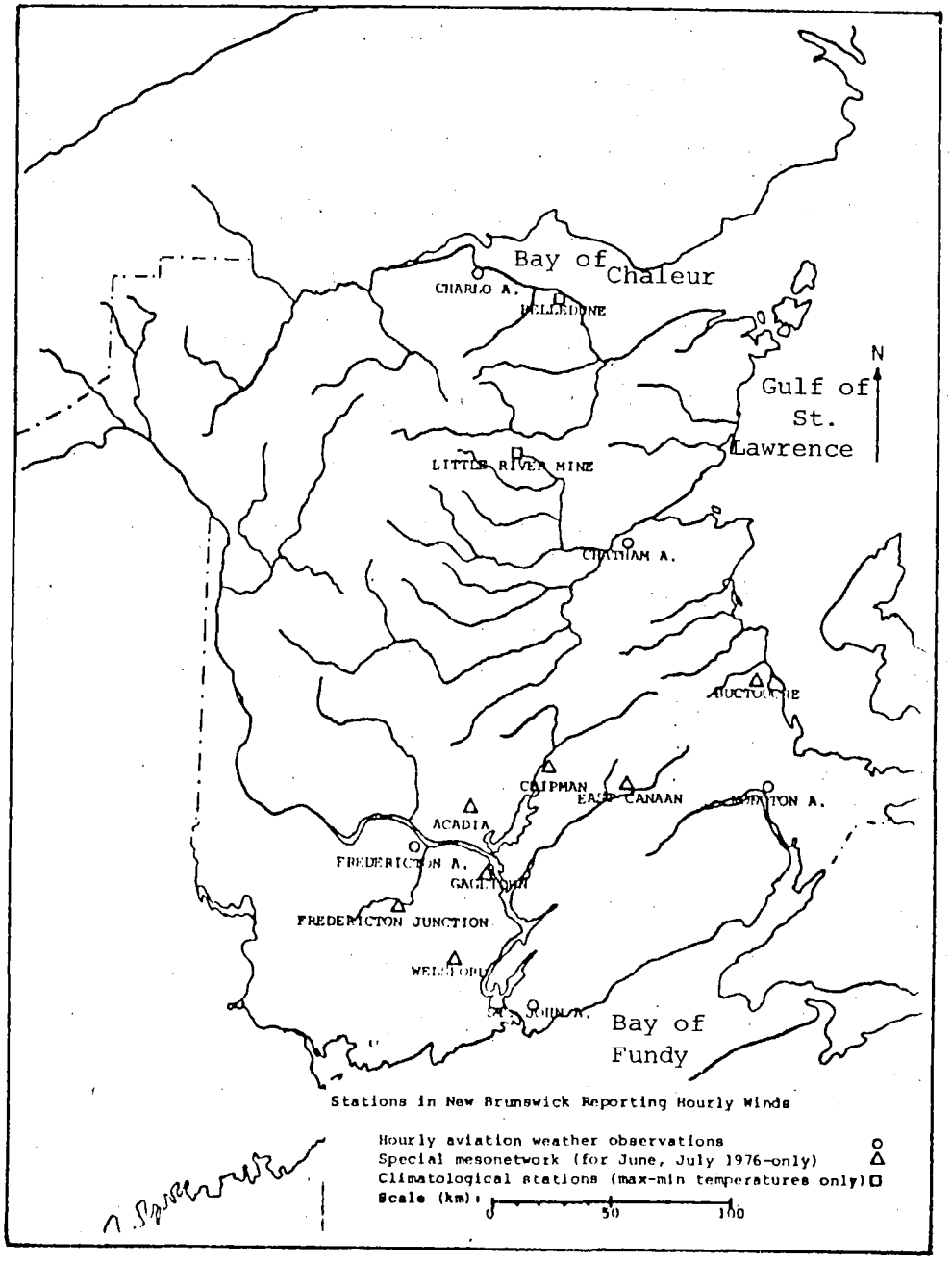

Figure 2. Map of New Brunswick showing locations of surface observing stations providing hourly winds.

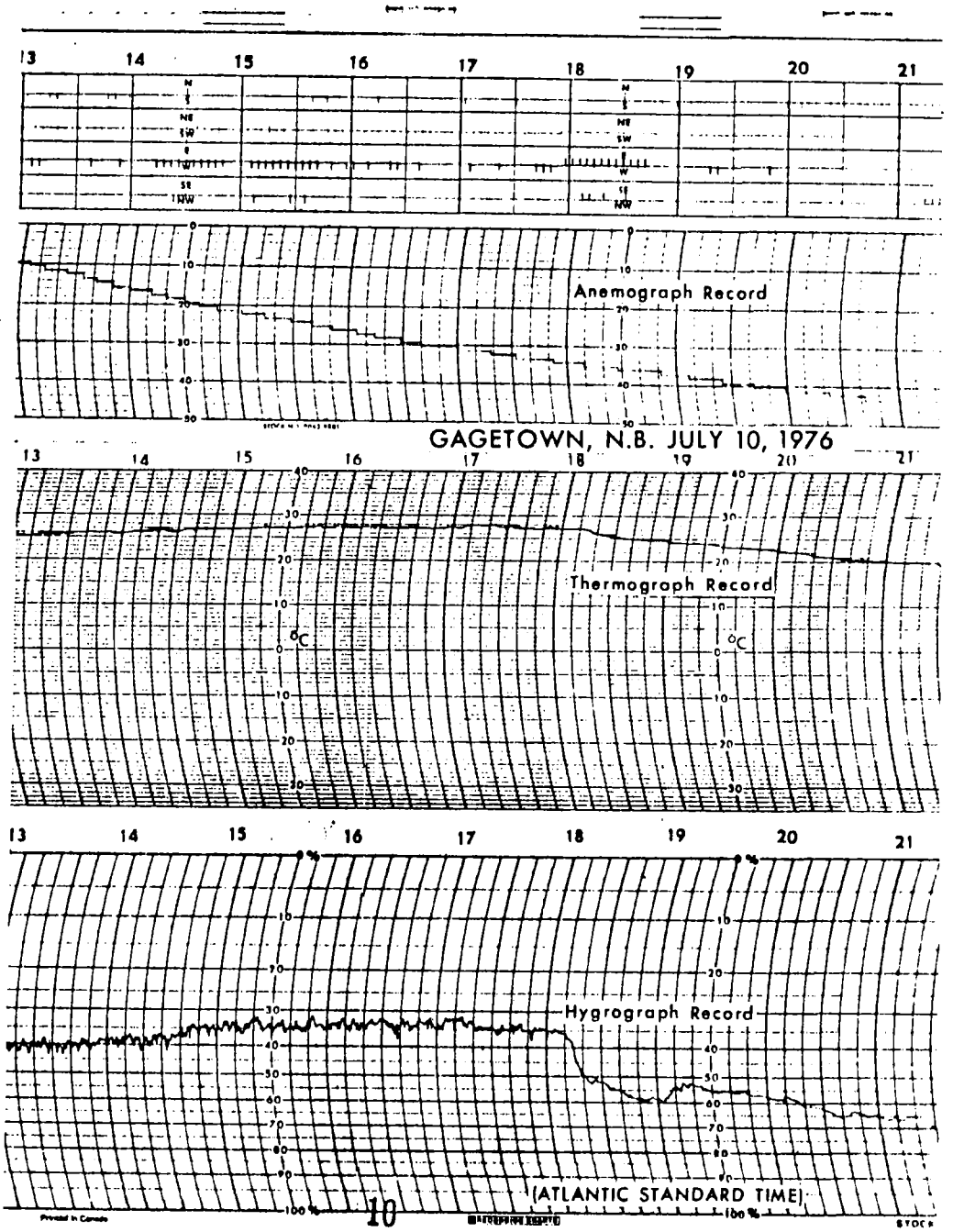

Figure 3. Anemograph, thermograph and hydrograph records showing discontinuity associated with passage of sea breeze front at 1810 AST, July 10, 1976 at Gagetown, N.B. This discontinuity is typical daytime sea breeze frontal passages in New Brunswick.

TABLE 1.

SEA BREEZE FRONT CHRONOLOGY - JULY 10, 1976

ORIGIN: BAY OF FUNDY

TIME (ATLANTIC STANDARD)	STATION	DISTANCE INLAND (KM)	DETAILS
1100	St. John Airport	11	Wind Shift and Increase SW 3 to SSW 13 Temperature Becomes Steady
1545	Welsford	32	Temperature Drop (2°C) Relative Humidity Jump (10%)
1810	Gagetown	63	Wind Shift W 4 to ESE 4 Temperature Drop (2°C) Relative Humidity Jump (15%)
1810	Fredericton Junction	64	Wind Shift NW 6 to SW 8
2030	Fredericton Airport	80	Wind Shift and Increase WNW 6 to S 14
2055	Acadia Forestry Station	95	Wind Shift and Increase WNW 3 to S 6 Line of Moths Observed on Radar

Acadia at 2055, an event which was accompanied by a line of spruce budworm moths observed on radar. Minisondes at Acadia (Figure 4) showed the arrival of the seabreeze to be marked by several degrees Celcius cooling, a windshift from west south southwest and a distinctive wind maximum in the lowest 300 to 400 M. On July 7, 1977 similar evidence of a deep seabreeze excursion from the east coast was obtained. Surface observations are summarized in Table 2. Seabreezes were detected at both coasts but only the east coast event showed deep inland movement and was detected 88 km inland by 1950 AST. Minisondes at Chipman, about 110 km inland, indicate arrival of the sea air between 2100 and 2300 AST by a wind shift from uniformly northwesterly to easterly in lowest 300 M of the ascent (Figure 5).

5. FREQUENCY AND PREDICTION OF SEABREEZES

Analyses for seabreezes were only performed for days for which inspection of 6 hr surface analyses excluded the presence of synoptic scale fronts or other convergence features, and which were predominantly sunny (solar radiation at least 40% clear sky values). Days with general off-water flow across the province were also excluded because, although a definite marine layer developed, the discontinuities and convergences at the leading edge of the cooler air were less pronounced than those with seabreeze frontal passages, and moth concentrations were not observed in conjunction with them. During the late June to early July periods of minisonde releases in 1976 and 1977 (27 days) seabreezed were detected on 37% of the days and estimated seabreeze frontal penetration had a median value of 40 km.

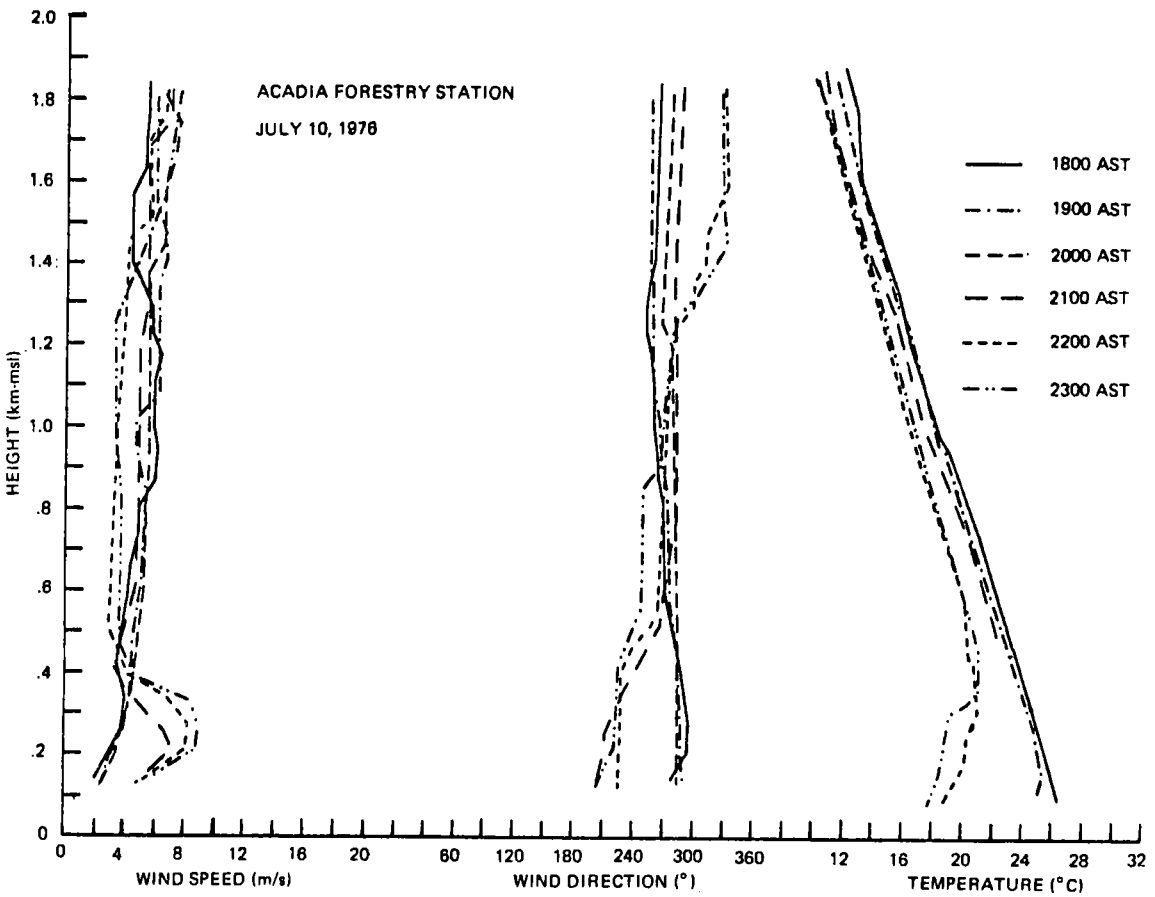

FIGURE 4. Wind and temperature profiles at Acadia Forestry Station, New Brunswick for July 10, 1976. The change in the lowest 400M from 2100AST onward is due to passage of a sea breeze from the Bay of Fundy.

TABLE 2

SEA BREEZE FRONT CHRONOLOGY - JULY 7, 1977

ORIGIN: BAY OF FUNDY

TIME (ATLANTIC STANDARD)	STATION	DISTANCE INLAND (KM)	DETAILS
1430	St. George	7	Wind Shift SW 11 to SE 11 Temperature Drop (1°C) Relative Humidity Increase (5%)
1500	St. John Airport	11	Wind Shift WNW 16 to SW 25 Temperature Drop (2°C) Relative Humidity Increase (5%)
1940	Welsford	32	Wind Shift WNW 6 to SSE 1 Temperature Drop (1°C) Relative Humidity Increase (5%)

ORIGIN: NORTHUMBERLAND STRAIT

1230	Buctouche	4	Wind Shift WNW 19 to ENE 11 Temperature Drop (1°C) Relative Humidity Increase (8%)
1500	Moncton Airport	23	Wind Shift NW 13 to NE 13 Relative Humidity Increase (5%)
1950	East Canaan	88	Wind Shift WSW 5 to ENE 3 Temperature Drop (1°C) Relative Humidity Increase (10%)

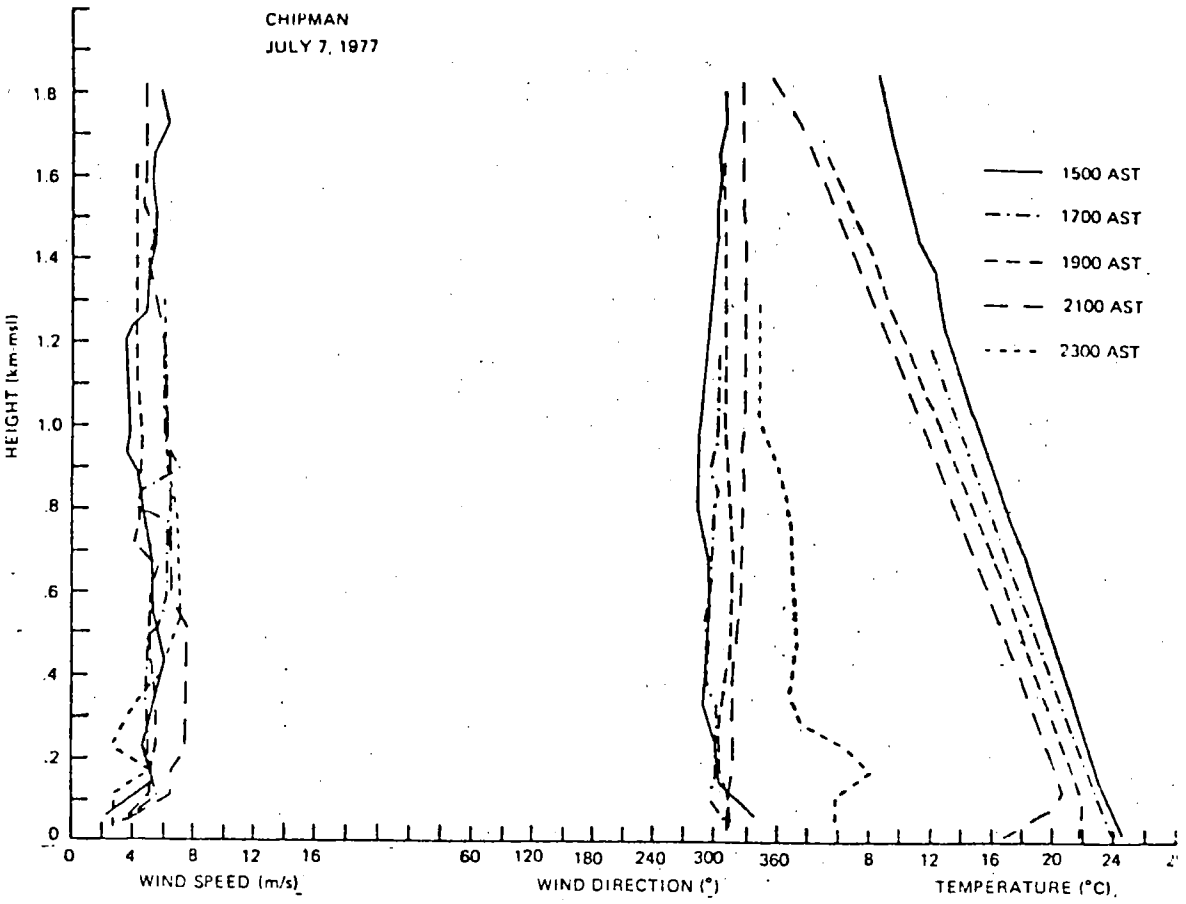

Figure 5. Wind and temperature profiles at Chipman, New Brunswick, July 7, 1977. The change of wind direction to ENE below 300 m in the 2300 AST profile indicates the passge of a sea breeze from the east coast.

Along the east coast, an analysis from seabreeze occurrence for all of June and most of July, 1976 and 1977 was also performed incorporating the observations from Charlo Airport and Belledune along the coast of the Bay of Chaleur. This is summarized in Table 3. For the 106 days analysed, at least one of the coastal stations showed a seabreeze on 28% of the days, but only 6% reached Moncton and only one reached Chipman. Biggs and Graves (1962) have developed an index to predict lake breeze occurrence based on land-sea temperature difference and wind speed inland to which Lyon (1972) added a minimum sunshine requirement (40% clear sky). When this was applied to the above data (Table 4) using Chatham as the representative inland location and average sea surface temperatures, it was 89% successful in delineating days of seabreeze at one or more of the coastal stations and 67% successful if only a particular station is considered.

The presence of a marine layer of cooler, denser air should be reflected in increased surface pressure above that expected from the synoptic situation. (Neumann et al, 1979). For sea air a few hundred meters depth and about 10°C cooler than inland air, this increase is in the order of 1 hpa. By excluding situations with instability lines, troughs, ridges or fronts crossing the area, a linear relationship between pressure and distance could be established at synoptic hours during July 1975 for synoptic stations on two transects through St. John, New Brunswick for all stations except St. John. The discrepancy at St. John was distinctly positive and was at maximum during the day. Examination of selected individual cases of high discrep-

Table 3

Detected sea breeze occurrences along east coast of New Brunswick during June and July 1976-1977

	Total Period	At any coastal station	Sea Breezes Detected Passing Moncton	Passing Chatham	Passing Chipman
No. of days	106	30	6	2	1
Percentage	100	28	6	2	1

Table 4

Comparison of predictions of lake breeze Index of Biggs and Graves with detected east coast sea breezes in New Brunswick

	Any station		Belledune		Buctouche		Charlo	
	S-B	No S-B	S-B	No S-B	S-B	No S-B	S-B	No S-B
Sea Breeze Predicted	26	1	19	8	15	12	21	6
Sea Breeze Not Predicted	3	7	3	7	0	10	3	7
Accuracy	89%		70%		59%		70%	

ancies during July 1976 to 1978 showed these days to have well established marine layers, either due to seabreezes or simple advection. Detection of marine flows by these pressure anomolies is readily adaptable to computer analysis of readily available synoptic meteorological data and could provide an initial step for screening historical data for seabreeze occurrence.

6. SUMMARY

The analysis of data from the mesonetwork in New Brunswick has shown that seabreeze fronts from either coast do periodically penetrate as far inland as 100 km and are probably responsible for the line concentrations of spruce budworm moths observed on the entomological radar. Near the coast seabreezes have been found to be quite common during the spruce budworm moth season from late June to mid July and these occurrences can be detected or predicted reasonably well from available synoptic data. The deep seabreeze pentrations of 100 km or more appear to occur only on the average once per moth season based on the radar observations and analysis of two years of mesonetwork data and so derivation of diagnostic techniques for these events is hampered by limited data. Completion of analysis for 1978 as well as data to be collected in 1979 should greatly help this process.

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DISCUSSION/COMMENTS

J.W.S. YOUNG: Are the other data sets at other areas other than Chipman available?

H. NEUMANN: Yes, just contact me personally. Except 1978 is not quite finished being processed.

L.A. BARRIE: Have you any observed line concentration incidences that you have documented sea breeze fronts for?

H. NEUMANN: The July 10, 1976 case. We documented the sea breeze, and there was a line formation on radar that day. Fortunately we didn't really start this intensive study until 1976 and that was the last year that the radar was in operation.

ATIKOKAN STUDY

C.S. MATTHIAS
Air Quality Assessment Section

INTRODUCTION

In the fall of 1977, the Department of External Affairs of Canada requested a modelling study of the effect on air quality of a proposed coal-burning electrical generating station at Atikokan, Ontario. The study was carried out jointly by the Atmospheric Environment Service of Environment Canada and the Ontario Ministry of the Environment.

The request for a detailed study developed because of American concern over possible degradation of their national parklands just across the border in Northern Minnesota. They felt that SO_2 concentrations from a large coal-burning plant with no scrubbing equipment would exceed their ambient air quality standards and that deposition processes would add significant acidity to the soil and water over many years. The increased acidity would reduce the numbers of sensitive plants, insects, and fish, and by altering the balance of nature, would reduce its potential to be an untouched, unaffected wilderness area.

Atikokan is only 61 km away from the border at its closest point (Fig. 1). The proposed power plant is to consist of four 200 megawatt units. With all units operating and burning the worst coal under consideration, the SO_2 emission rate will be 2590 grams per second or 81,700 metric tons per year.

Our modelling examined the change in ambient air quality at several border points. For an estimate of the annual average SO_2 concentration, the Climatological Dispersion Model (CDM) was used. For hourly SO_2 concentrations, we calculated the range of values to be expected over a period of a year using two models: a statistical model, and a Mixed Layer Gaussian model.

THE MIXED LAYER GAUSSIAN MODEL

The lower part of the planetary boundary layer can usually

be characterized as a turbulent layer having reasonably uniform wind velocity and turbulence, extending from the ground up to an inversion or stable layer, characterized by a lack of turbulence. Using twice daily radiosonde data over a four year period, Portelli (1977) calculated the maximum mixed layer height L for each day, and the mean wind speed U and direction α through the layer at this time. These have been arranged into joint frequency distributions (JFD's) of U vs α, U vs L, and L vs α, using data from all the Canadian radiosonde stations and the northern U.S. stations. A joint frequency distribution specifies the number of days (absolute measure) or the fraction of days (relative measure) that a given combination of the two variables occurs.

The closest radiosonde station to Atikokan, Ontario, is in International Falls, Minnesota. Mixed layer statistics from this station were used and were felt to be climatologically representative, having been developed from four years of data. The Gaussian model requires only a wind speed and a mixing height to make a centerline concentration calculation . The mixing height was assumed to grow linearly from zero at one hour after sunrise to the maximum value L at 1400 hours, remaining there until one hour before sunset when it drops to zero again. Plume rise formulae and dispersion coefficients σy and σz developed by Briggs were used. Stability categories were determined by the wind speed and estimates of insolation.

The 24 hour average concentration is determined by averaging the hourly concentrations, which vary with mixing height, over a 24 hour period. The mixed layer wind speed was assumed to be constant and in the same direction during this time. Since the σy's and σz's are hourly averaged, an adjustment must be made to χ to account for the extra broadening in σy due to meandering during the period.

The JFD of U vs L is constructed from winds blowing in all directions. We assumed that it would be comparable to the JFD's blowing in the directions of interest for this study, ie., from ENE to NNW. The JFD of U vs L for the summer months of June, July, and August is shown in Table 1. For each season, calcula-

tions were made for all combinations of U and L that have non-zero frequencies. For a wind speed of 3 m/s and L = 1100 m, there are 12 days out of a total sample size of 365 days that have identical characteristics. Knowing the range of concentrations for each U-L combination and the frequencies of their occurrence, the concentrations can be arranged in descending order from which a seasonal cumulative frequency distribution (CFD) can be made.

An annual cumulative frequency distribution is prepared by calculating concentrations for all seasons and arranging them in descending order. The CFD of hourly averaged concentrations is shown in Figure 2. The line drawn through the points indicates the percentage of time that a given concentration is exceeded. From this curve, we can estimate the highest hourly concentration likely to be experienced during a year. If we are interested in the border point 61 km downstream in the NNE sector from Atikokan, the mixed layer statistics tell us that the wind blows in this direction 4.7% of the time. In one year then (8760 hours), the wind blows for 412 hours in this direction. One of these hours will have the highest concentration. The highest concentration will be equalled only once, with a frequency of 1 hour out of 412 or .24%. The second highest concentration will be equalled or exceeded only twice, with a frequency of 2/412 or .48%. From Fig. 2, we can read the highest and second highest concentrations to be 120 and 110 $\mu g/m^3$.

Repeating this analysis for the 24 hourly averaged concentrations allows us to calculate the highest value at the same border point to be 19 $\mu g/m^3$. The second and third highest concentrations can be found in a similar manner to be 13.5 and 10.5 $\mu g/m^3$. All these concentrations exceed the American Class I wilderness area 24 hr. SO_2 standard of 5 $\mu g/m^3$.

The mixed layer model is currently being modified to improve the calculation of the mixed layer height and the determination of the stability category.

The net result of the study indicated that all concentrations were within Canadian maximum desirable limits, and exceeded the American Class I standards only a few times each year.

THE STATISTICAL MODEL

The idea behind the statistical model is to take advantage of the knowledge of frequency distributions of concentrations that have been measured in many places. A great deal of work has been done by Ralph Larsen of EPA (1969) in assembling urban air pollution data and presenting it graphically. His figures show very clearly the linear trend of a CFD for a given averaging time when plotted on long-normal graph paper. It was felt that a similar approach would be suitable for the point source at Atikokan.

The meteorological input consisted of a 10 year record of hourly surface data measured at Atikokan. The data were processed by the STAR Program which produces a JFD of wind speed and direction for each month and each Pasquill-Gifford stability class. By choosing a specific direction, the JFD of wind speed vs stability class could be formed for this direction. Since there are 6 wind speed classes and 7 stability classes, there was a maximum of 42 combinations, each having a different frequency of occurrence. Calculating the concentrations at the border using a Gaussian model for each combination, ordering them according to magnitude, and forming a CFD, the results were plotted on log-normal paper. Using Larsen's scheme, a straight line was drawn through the points and the highest and second highest concentrations were extracted. The results were comparable to those of the mixed layer analysis.

CONCLUSIONS

Two models were used in this study: one a mixed layer model using climatological mixed layer statistics as input, and the other a statistical model using hourly surface data processed by a STAR program. Both models were assembled in haste for this study and are capable of much improvement. The significant output information is comparable to that of the EPA models CRSTER and RAM, which are far more demanding in terms of computer power and input data.

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Table 1.

Summer Joint Frequency Distribution of Wind Speed vs. Maximum Mixing Height Developed From Four Years of Data (July 1965-June 1969) (Sample Size = 365 days)

Mixed Layer Wind Speed U (m/s)	Maximum Mixed Layer Height L (meters)											
	0	0-200	200-400	400-600	600-800	800-1000	1000-1200	1200-1400	1400-1600	1600-1800	1800-2000	2000+
0-2	0	0	3	3	0	1	2	0	0	1	0	1
2-4	0	2	5	5	4	2	12	10	8	8	5	12
4-6	0	5	0	6	9	7	8	8	9	9	9	23
6-8	0	1	2	5	7	3	9	8	5	10	6	27
8-10	0	1	2	2	7	4	4	6	9	6	2	13
10-12	0	0	0	0	3	4	2	3	2	2	0	11
12-14	0	0	0	1	1	0	0	2	4	3	1	2
14-16	0	0	0	0	0	0	0	0	1	0	1	4

Fig. 1 International Border near Atikokan

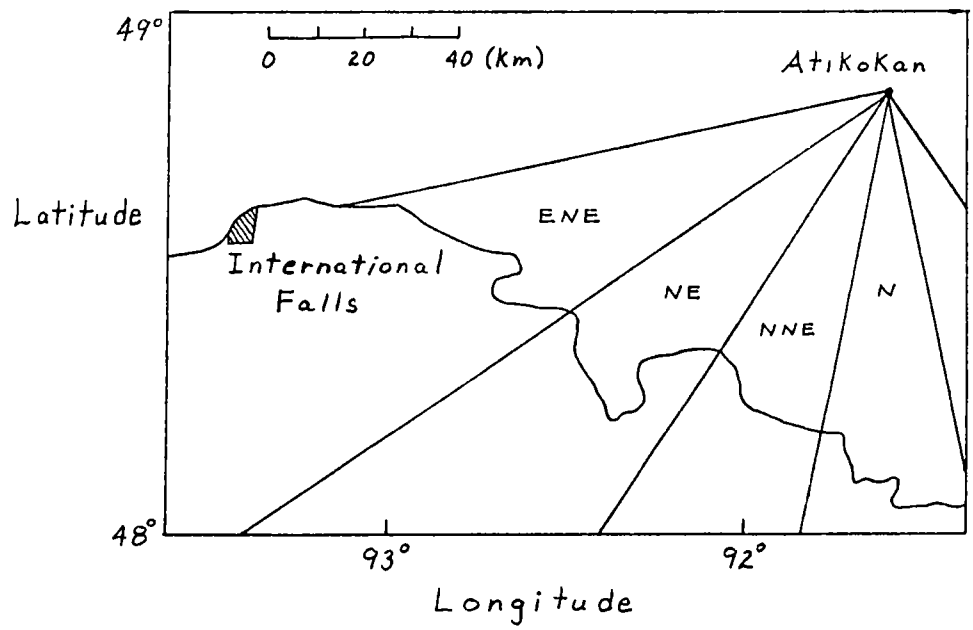
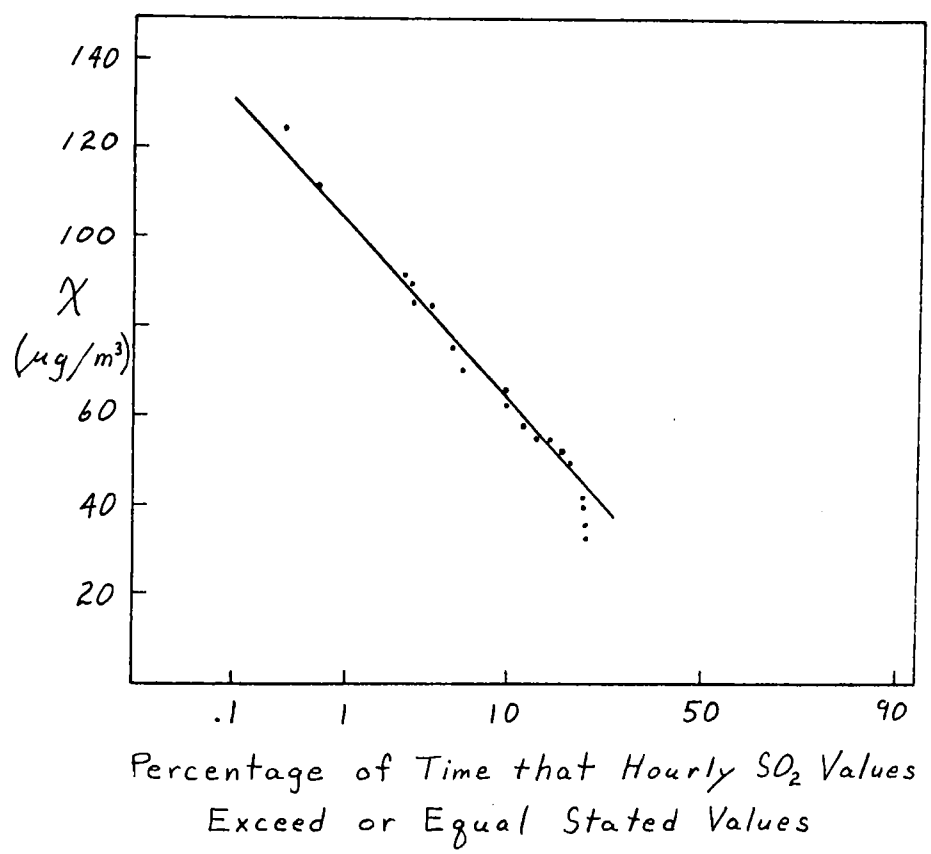


Fig. 2 Annual Cumulative Frequency Distribution for χ (hourly averaged), 61 km. Downstream



DISCUSSION/COMMENTS

J.W.S. YOUNG: Have you compared the results from these two models against CRSTER or RAM that use the actual hourly observations, and if so, how do they compare?

C.S. MATTHIAS: The Americans did a study at the same time as that done by the Ontario Ministry of the Environment and ourselves. They used the RAM model, and their concentrations came out to be lower than ours, in most cases. We exceeded their standards several times, whereas I'm not sure how frequently they exceeded the standards. I guess they did so a few times, but our concentrations were consistently higher. The reason for that is simply in the design of the two models. Our modelling effort was more conservative in our assumptions, so all our concentrations would be expected to be higher.

D.M. WHELPDALE: Can you tell me what the criterion was for using the model to assess this situation. Was it the number of exceedances of the American wilderness area standard in a certain period of time?

C.S. MATTHIAS: We planned to estimate the range of concentrations to be expected over a year's period to see how frequently American standards would be exceeded. There was no attempt at modelling deposition or other effects, simply hourly concentrations over the yearly period.

D.M. WHELPDALE: That's the reason I bring this up, because I think initially the Americans thought on the basis of air concentrations there would be some problem, but since then they have gone more to the possibilities of high depositions, and that means that we will probably have to go that way too, and assess probably not the impact, but assess the loading rates. Can these modelling approaches handle that kind of requirement?

C.S. MATTHIAS: Yes, if you refer to Gaussian modelling or this type of modelling it's quite possible to make estimates of deposition loading over a long period of time. Since the accuracy of specifying exactly where the loading has to be diminishes over the long time period, the Gaussian approach will give a reasonable estimate.

R.V. PORTELLI: I'd just like to point out a couple of things. One, the approach that Chuck has used; I think there is an important distinction to note. It's a climatological or statistical approach, and it is much simpler to use than the brute force CRSTER or RAM approach which goes hour by hour for a year. This type of evaluation, in my mind, indicates that we might be able to do studies like this at a lower cost or lower effort, once everything is running smoothly on a computer. Chuck has a number of improvements that I think he will be able to incorporate, and as he said, the approach itself was necessarily conservative because of some of the assumptions. I think it is also worthwhile to mention that the U.S. did use that RAM model and as described by John Walmsley it is fairly complex computationally. They also have subsequently gone into another study as Doug (Whelpdale) has mentioned, to determine deposition, and in this study they used a grid model, a much more complex grid model, where they incorporate transformation rates, depletion terms, and in this case I'll just quote the three numbers that I recall. The model that was described here predicted a maximum 24 hourly concentration of 19 micrograms per cubic meter, the RAM model predicted 7 micrograms per cubic meter, and the U.S. recent

indepth study predicted 12, at about 62-63 kilometers from the source on U.S. soil, and all of Chuck's data I believe pertain to that spot. A lot of attention has to be paid to the study Chuck has just given because you have to really evaluate how much effort you're going to put in to doing an assessment. This is not talking about doing a research investigation. When we are asked to do this, we don't have much lead time. Chuck, I believe, had six weeks to mount all this effort, and a lot of it had to be done from scratch. There were some basic models and the data sets. There was another question from a consultant as to what type of data sets are available or should be used, and I think this has been illustrated here too.

L.A. BARRIE: I have a question concerning the applicability of Briggs dispersion coefficients in a forested area. Are they really applicable?

C.S. MATTHIAS: As it turns out the dispersion coefficients that we used over rural terrain only described a surface roughness of 3 centimeters. Over a forested area we should use a surface roughness characteristic of perhaps 1 meter, which probably would mean we should have used the urban curves, or modify the Briggs curves so that they represent the increased surface roughness. Certainly future studies should take this into consideration.

L.A. BARRIE: I guess to put my question another way; are there any accepted and experimentally proven set of dispersion coefficients for a forest canopy?

J.W.S. YOUNG: There are some that were developed by the Travellers Research Group which are not very widely used. They're used in the Toronto model. I can make those available to you if you want.

L.A. BARRIE: You mention, Chuck that the results of your modelling was that the air concentrations were within the Canadian standards. Were these with respect to the 61 kilometer point or was this closer in to the Atikokan Plant as well?

C.S. MATTHIAS: That was at the 61 kilometer point. Closer in studies have been done earlier. Acres Consultants, Ltd. did a study for Ontario Hydro, and I believe they found that the concentrations were below Canadian standards anywhere downwind of the plant.

THE LONG-RANGE TRANSPORT OF AIR POLLUTANTS

H. C. MARTIN
Boundary Layer Research Division

INTRODUCTION

The Long-Range Transport of Air Pollutants (LRTAP) and its associated phenomena, is perhaps the most pressing problem confronting environmental scientists in North America today. This paper discusses the problem and the Federal program currently underway to study the problem. The first section describes how the problem was first detected in Europe and the development of subsequent studies in North America. The second section describes the various components of the federal program. The final section gives a brief prognosis which touches upon both the political and economic implications.

Long-Range Transport is the movement of pollutants through the atmosphere by the winds over large distances. This phenomena does not introduce any new physical or meteorological processes. However, the study of LRTAP differs significantly from the conventional study of local pollution for several reasons: first, the concentrations of pollutants encountered in LRTAP are generally within air quality standards and in some cases below conventional detection limits, second, the regions in which the pollutants are deposited are at distances of the order of 1,000 km from the sources, and third, the specific sources which are responsible for the pollutants are not identifiable. One of the most common terms associated with LRTAP is acid rain, or more correctly, acidic precipitation. Acidic precipitation describes the chemical nature of precipitation which is more acidic than normal. As pollutants move through the atmosphere over long distances, they react chemically with the water vapour naturally found in the atmosphere and produce acidic water vapour. Sulphur dioxide and nitrogen dioxide are the two main constituents responsible for the acidification of precipitation. In North America, it is thought that sulphur

dioxide is responsible for about two-thirds of the acidity in precipitation while nitrogen oxides are responsible for about one-third. The sulphur dioxide is mainly a product of ore smelting industries in Canada while in the United States it comes primarily from power generation. Nitrogen oxides come from the transportation industry.

About twenty years ago scientists in the Scandinavian countries observed that the acidity of fresh-water lakes and streams was increasing. The acidity increased over the years to a point where large numbers of lakes were no longer able to support fish populations. From these studies it was determined that the cause of the deterioration in fresh-water systems was not local industrial activities. The source of the problem lay in the industrialized areas of Central Europe and Great Britain. Three elements were present and created an LRTAP problem: there were large regional sources of pollutants in Central Europe and Great Britain, meteorological conditions which transported the material to remote areas and, finally, these remote areas were sensitive to the impact of low, continuous, concentrations of pollutants, primarily sulphur dioxide and nitrogen oxides. These regions are called sensitive receptors.

In North America we have a parallel situation. We have large sources such as St. Louis and the Ohio Valley in the United States and Sudbury, Toronto and the industrial St. Lawrence Valley in Canada. The meteorological conditions carry the pollutants from the sources over long distances into the remote and sensitive regions of Ontario, Quebec, the Maritimes and in the United States to the Adirondacks. Table 1 gives the annual emission estimates of SO_2 for Eastern North America and compares them with the European and Global emissions. Eastern North America produces about one quarter of the world total emission. This SO_2 load is a precursor to acid rain. In Eastern United States there are indications that the acidity of precipitation is increasing. The work of Likens (1976) showed that over a 17 year period from 1955 to 1972 not only did the mean pH of precipitation in Eastern United States decrease but that the area ef-

TABLE 1

MAN-MADE SULFUR DIOXIDE EMISSIONS

(UNITS ARE TG SO_2/YEAR)

AREA	YEAR	EMISSION	PERCENTAGE OF GLOBAL
GLOBAL	1970	130	100
EUROPE	1973	50	38
UNITED STATES	1972	30	23
CANADA	1974	6	5
EASTERN NORTH AMERICA	-	30	23
ONTARIO	1974	2.4	2
SUDBURY AREA	1977	1.4	1
ONTARIO HYDRO	1976	0.37	-

(D.M. Whelpdale - private communication)

fected by increased acidic precipitation increased. Furthermore, it has been shown that the rate at which the pH of precipitation is decreasing is more rapid than the decrease observed in Scandinavia and, secondly, that the remote sensitive areas in North America being subjected to acidic precipitation are more sensitive than those in the Scandinavian case.

THE FEDERAL PROGRAM

The study of LRTAP is very complex and requires an interdisciplinary approach. As much as possible co-operation has been sought with scientists in the Provincial Government, in the universities, and in the United States. The unifying theme throughout this program is the examination of sulphur and sulphur compounds. These compounds were selected because they are known to be causing damage over large areas of Eastern North America because a great amount of effort has gone into the study of these compounds in the Scandinavian context and their results may be used in North America, and finally, because the energy policy of the United States requires a shift to coal-fired power plants and a subsequent increase in the atmospheric sulphur load.

The program has been broken into four somewhat arbitrary parts. The four parts are: Emission Inventories, Atmospheric Transport and Transformation, Aquatic Effects, and Terrestrial Effects.

(a) Emission Inventories

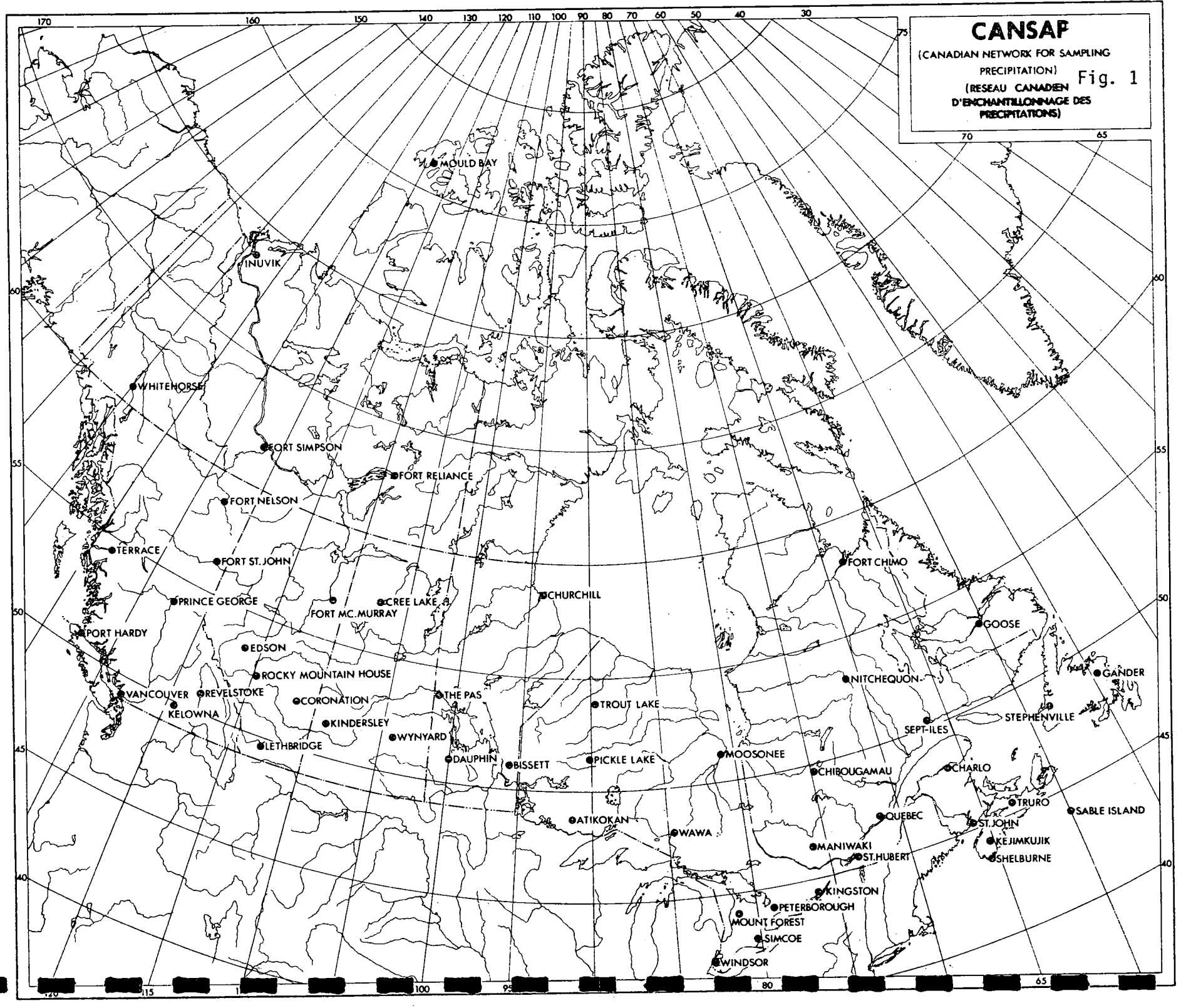
An emission inventory for SO_2 has been essentially completed for Eastern North America. Area sources are provided on a grid which is compatible with U.S. data banks. Large sources are specified by location and stack parameters. Attention is now being directed to obtaining an inventory for natural SO_2 emissions for the study area. This inventory should be available within one year. In addition, inventories are being developed for both nitrogen oxides and mercury. At the same time it is hoped that the sulphur dioxide inventories may be improved to the point where seasonal variations would be available.

These inventories are essential to modelling activities. They provide the basic input data which are used by modellers to generate deposition fields in the susceptible areas. In addition, the regular updating of inventories for Eastern North America provides information necessary to determine trends in atmospheric loading, and could provide an indication of the effectiveness of control technologies.

(b) Atmospheric Transport and Transformation

Perhaps the most widely known project in the Federal LRTAP Program is the CANSAP Network (see Figure 1). CANSAP stands for Canadian Network for Sampling Precipitation. This network was started in 1973 and now is composed of 51 stations located across Canada. The monthly precipitation sample from each station is sent for analysis to the laboratories at the Canadian Centre for Inland Waters, Burlington. The samples are analyzed for pH, specific conductants and for the major ions. Because the network has been in operation for a short period of time it is not yet possible to determine trends in precipitation pH such as those described by Likens for the Eastern United States.

The instrumentation and analysis procedures used for the CANSAP samples are now being intercompared with American instruments and analysis procedures. By using this intercomparison information it should be possible to integrate data obtained from American and Canadian precipitation networks, thereby obtaining synthesized maps of precipitation acidity for the whole Eastern part of the continent. It is particularly important that the CANSAP network be integrated with the National Atmospheric Deposition Project which is currently coming on line in


CANSAP
(CANADIAN NETWORK FOR SAMPLING PRECIPITATION)
(RESEAU CANADIEN D'ENCHANTILLONNAGE DES PRECIPITATIONS)
Fig. 1
MOULD BAY
INUVIK
WHITEHORSE
FORT SIMPSON
FORT RELIANCE
FORT NELSON
TERRACE
FORT ST. JOHN
PRINCE GEORGE
FORT MC. MURRAY
CREE LAKE
CHURCHILL
FORT CHIMO
GOOSE
PORT HARDY
EDSON
ROCKY MOUNTAIN HOUSE
VANCOUVER
REVELSTOKE
KELOWNA
CORONATION
THE PAS
TROUT LAKE
NITCHEQUON
GANDER
STEPHENVILLE
KINDERSLEY
WYNYARD
SEPT-ILES
LETHBRIDGE
DAUPHIN
BISSETT
PICKLE LAKE
MOOSONEE
CHIBOUGAMAU
CHARLO
TRURO
SABLE ISLAND
ATIKOKAN
WAWA
QUEBEC
ST. JOHN
KEJIMKUJIK
MANIWAKI
ST. HUBERT
SHELBURNE
KINGSTON
PETERBOROUGH
MOUNT FOREST
SIMCOE
WINDSOR

the United States.

The Air Precipitation Network (APN) is composed of six stations in Eastern Canada. The sampling procedure differs from the CANSAP network, in that samples are taken everytime there is a precipitation event. The sites are generally chosen to coincide with locations where other intensive LRTAP studies are underway.

If one has a model which describes the physical and chemical processes occurring in the atmosphere as air flows over the study area then, given the emission inventory for the whole study area, it should be possible to predict the deposition field at a remote site, while taking proper account of inputs from outside. Such an operational model for the long-range transport of air pollutants has been developed. At the moment, there is a need for considerable refinement of the parameters describing the transformation processes which occur during transit from emission source to deposition site, and in the deposition parameters as well. Verification of the model requires not only deposition information such as that provided by the CANSAP network but also dry deposition data and estimates of concentrations of various constituents during transit. The latter verification of the model involves aircraft sampling at varying distances from regional sources.

In 1980 Canadian scientists involved in the Long-Range Transport Program will participate in an American EPS Study called The Prolonged Elevated Pollution Episode Program (PEPE). The planned field measurements and monitoring activities will provide validation data for the operations model being developed in the National Program. The study will also give in situ measurements of the transboundary fluxes of sulphur compounds at the Canadian-United States border. This information is of interest in that it relates to regional budgets such as the one reported by Whelpdale and Galloway (1979) for

Eastern North America.

(c) Aquatic Effects

Recent publicity has focused great attention on the deterioration of fresh-water lakes and streams caused by acidic precipitation associated with the long-range transport of air pollutants. This effect is perhaps the most remarkable and disturbing consequence of LRTAP. It has been estimated that in Ontario alone, forty-eight thousand lakes are in sensitive areas and are potentially in danger of being significantly altered by acidification due primarily to sulphur and sulphur compounds in the atmosphere transported from distant sources. In some areas, studies have been underway for the last ten years documenting the progressive deterioration of water sheds. The case of the LaCloche Mountain Lakes of Ontario is noteworthy. The impact of lake acidification on fish populations at this site is reported by Beamish and Harvey (1972). The results obtained from this study are not entirely applicable to the LRTAP problem, since, the site is within sixty-five kilometers of Sudbury and the measurements were made before the tall stack was constructed. Consequently, the impact on the LaCloche Lakes has been due to a local sources, the Sudbury Smelter. In a sense the effects of acidification in this area have been telescoped in time when compared to effects to be expected in remote regions, though this extrapolation to other areas must be done with some caution. The study of the LaCloche Lakes showed a continuous deterioration in fish populations over the period for 1961 to 1971. During this time the pH of the study lakes was decreasing. The number of species in specific lakes decreased from year to year. At the same time, for any one species, the age distribution was often not uniform but rather, year classes started to disappear sometimes among the older fish and sometimes among the fry.

Once the pH of a lake reached 5 and remained there

or decreased further, nearly all fish species were in danger or had disappeared. Lakes without any fish normally had a pH below 5. It is speculated that at the present loading rates as determined by the CANSAP data, great numbers of lakes in sensitive areas will be in very serious danger within ten to twenty years, that is, their pH values will be approaching 5 or will have fallen below this value.

Because of the commercial and recreational value of fresh water fishing, this segment of the aquatic flora and fauna is given considerable emphasis. However, acidification of water systems impacts on the total ecological community. This disruption of the aquatic ecosystem is only partly understood. The National Program is focusing specifically on water chemistry including surface runoff and ground water. In addition, fish studies are underway and it is proposed that the salmon fisheries in the Atlantic Region be examined to assess the impact of stream acidification upon fish during their spawning period and youth in the fresh-water streams in that area.

One of the more urgent studies to be undertaken is an examination of the impact of spring melt on watersheds. During the six or seven months of winter precipitation, snow accumulates on the ground often without melting until the first melt in spring. At that time the materials that have been deposited are selectively flushed out and flow into the streams and lakes with the result that the highest acidities occur with the very first melt. The impact of these very low pH values upon aquatic life particularly young fish can be disastrous and probably explains the disappearance of year classes in some fish species. The very acidic runoff water bathes the shallow spawning beds with water whose acidity may be toxic to eggs or fry.

With regard to remedial action that might be taken to recover acidified lakes it appears that many processes

which accompany acidification are in large part irreversible. It is true that by liming the water body, the pH may be raised to a value equivalent to the value that occurred when the lake was in its natural state. However, it is not possible to reverse all the synergistic chemical processes which have occurred during the lake deterioration. These processes include the mobilization of toxic chemicals from the sediments and the removal of the buffering capacity of the watershed soils. As a consequence of the latter process, subsequent acidic precipitation will flow directly into the lake without any neutralization by the calcarious overburden that was originally present. These processes may be studied artificially. The program is currently examining the impact of controlled acidification of several lakes at the Experimental Lake Area near Kenora (Schindler, 1979). At this site lakes are artificially acidified and the impacts on fish populations, water chemistry, sediments, and vegetation are examined. Subsequently, the lakes are limed and the changes that occur are monitored. The purpose of this study is not only to determine the effect of acidification on aquatic ecosystems, but also to evaluate the ability of the ecosystem to recover.

(d) Terrestrial Effects

The impact of LRTAP on terrestrial ecosystems is not as well understood or documented as the case of aquatic ecosystems. With regard to agriculture, the effect of sulphur compounds is probably very small because agricultural activities are normally carried out on well buffered, calcareous soils and, in fact, the fertilization of soils often involves the addition of sulphur. With regard to forestry, the effect is not well understood mainly because the time scale for detection is probably an order of magnitude longer than the time scale for detection of effects in the aquatic systems. In addition, changes in forest growth associated with acidic precip-

itation are difficult to quantify because of other influences which may effect forest growth, such as, harvesting paractices, insect damage, and climatic change. It is expected that changes in soil chemistry resulting from selective weathering or leaching by water with higher than normal acidity should have some impact on soil fertility and forest growth. These changes in soil chemistry are normally irreversible so that deteriorating fertility, for example, would have a negative impact on forest growth which would be permanent.

The National Program will include several laboratory studies of soil chemistry as well as the monitoring of soil monoliths at research sites where other aspects of the LRTAP problem are being examined.

(e) Calibrated Watersheds - Ecosystems

Because of the complex interrelationship between the various components of this problem it is essential that an interdisciplinary examination of all the components be undertaken at selected field sites. Such a site may be referred to as a calibrated watershed or a selected ecosystem. In the National Program three sites have been designated to date.

The Experimental Lakes Area north of Kenora has been in operation for several years. The work being undertaken there in controlled acidification has been discussed above. The study of water chemistry within the watershed of these lakes and within the lakes themselves has been ongoing as well as the examination of aquatic life. An Air/Precipitation stations is located there. Additional work is required to document the geology and vegetation cover in the area. It should be pointed out that this site is only marginally impacted by pollutants normally associated with LRTAP, being somewhat west of the region of greatest deposition.

A calibrated watershed at Kejimkujik Park has been established. The park is located in central Nova Scotia

and has been the site of various studies over the past 10 or 15 years. The data available from these studies is invaluable as it provides a historic record which can be incorporated into the current effort.

The third site identified is in the Montmorency Forest, in the Laurentides Park located about 100 kilometers north of Quebec City. This forest is managed by Laval University. The historical data set for this site includes meteorological data, snow cover data, surface water chemistry and runoff volume for a calibrated watershed within the forest, lake chemistry, soil chemistry, and vegetation cover surveys.

In each of these three cases the ecosystem selected has met to varying degrees several criteria. These criteria include, that historical data is available for various components of the LRTAP Study, that research facilities and accommodations are available for scientific staff, that there is easy access to the site which excludes the general public, and that the site will not be subjected to external forces such as industrialization or increased cottage activity during the period of the study. Typically, an ecosystem must be under examination for a period of about three years before information of value starts to appear. The costs for running such a study are extremely high but are offset by the very substantial benefits derived from this unified approach. It is only through an integrated examination of meteorology, geology, vegetation cover, water chemistry and fish and animal life that the impact of low concentration of pollutants carried from distant sources may be assessed.

DISCUSSION

The impact of air pollutants carried over long distances and deposited in low concentrations on sensitive receptors presents a new area of study. LRTAP may be considered the most serious environmental problem facing us today. It has several

characteristics which are cause for great concern:

(a) It is widespread and represents a regional problem
(b) the effects are insidious, operating in many cases in a slow and not easily apparent manner
(c) the effects in many cases are irreversible
(d) environmental damage does not appear in a sensational way, and
(e) there is evidence that the situation is worsening.

The purpose of the National Program is to examine the scientific components of the LRTAP Program. It is not the intention of these studies to evaluate the economic impacts nor the political issues involved. The economic impacts are extremely wide ranging. They include the total energy policy of this continent, the industrial activities in the eastern part of the continent and the recreational resource used by inhabitants within the region. We are concerned with an assessment of our quality of life. The political implications are equally complex. The inherent transboundary property of the airborne pollutants requires an examination of pollution control policies on both a provincial and international scale.

Perhaps the most distressing element of the LRTAP problem is time. Certain remote pristine ecosystems are undergoing changes which are generally recognized as undesirable. The rate of deterioration is significant, and in the light of current energy policies it is expected that the rate of deterioration will not decrease.

Implementation of solutions, once the scientific evidence and understanding is available, will take a considerable length of time even with the most sincere co-operation and goodwill on the part of all people concerned.

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DISCUSSION/COMMENTS

P.A. TAYLOR: When you showed the results for Croissant Lake, it looked like a seasonal thermocline formation taking place, and I wasn't quite sure why the spring runoff concentration was the same as the pH throughout the major portion of the lake, or was that just by chance?

H.C. MARTIN: I don't know, perhaps there's no turning over. I was only concerned with what was happening in the upper layer, which appears to happen in many of these lakes.

P.A. TAYLOR: It's happening because in the spring there is a mixing down of this runoff presumably, because the runoff is coming in cold, and so it's mixing right through the lake, whereas during the summer, you're getting warm runoff which is staying in the surface layers, and you're getting a seasonal thermocline established, through which there is very little mixing.

L.A. BARRIE: Cold water is lighter at $0^{o}C$ than at $2^{o}C$ or at $4^{o}C$. Then the density drops with increasing temperature, and so when the spring snow-melt hits the lake, it does form a cold acidic layer at the top until the lake water reaches $4^{o}C$ and then you get the turning over.

H.C. MARTIN: Well, to get the full picture you'd have to take the temperature of the runoff and the temperature of the lake, but presumably some time after runoff, a month or so after runoff, your runoff will be warmer than the lower portion of the lake, and you're still seeing that decrease in pH.

P.A. TAYLOR: A supplementary question is whether the lake acts to intensify the acidity or whether the maximum pH the lake will reach is in fact the pH of the rainfall.

H.C. MARTIN: Yes, the worst case would be what is coming in.

L.A. BARRIE: I think that as far as monitoring inputs of acidity to receptors it is important to emphasize that dry deposition contributes as much as 50% to the total, and that the best way we have of measuring dry deposition now is to measure the air concentrations and that we also are attempting this in our networks.

H.C. MARTIN: Or during the winter to examine snow surface deposition, which is another good way, but our understanding of dry deposition is I think much poorer than our understanding of wet deposition, merely from the fact that we can't measure it very well.

CLOSING REMARKS

R.V. PORTELLI

Air Quality Assessment Section

I would like to start off by saying that was a very good presentation (by H. Martin) to end up our workshop on.

This workshop was initiated in response to the regions' expressed air quality needs and in the workshop we have identified some further needs. I hope we can identify more in the future. It's been an opportunity to transfer some technology, and I personally benefited a great deal from listening to the various presentations that were given. The proceedings of this workshop will be published, and I think it should be noted that as a result of the commitment to put the proceedings together, an awful lot of work has gone into the preparations by many individuals. We also would like those regional people who are here, to note that it would be appreciated if some response with respect to workshop evaluation would come into our office.

I have one recommendation that I will definitely be making for the future. If we have such a workshop like this again, which I believe we will, that it should be open to the provincial and the industrial sectors; I believe that's one of the things we missed here having that dynamic interaction with others in the field who would be very interested in providing input. Beyond that, I think a lot of us have been able to appreciate the depth and breadth of expertise in this branch (the Air Quality and Inter-Environmental Research Branch) and the regions of AES. I certainly have thoroughly enjoyed it.

I would like to thank the speakers, the Chairpersons, Jim Arnold, who handled our audio visual, Ray Hoff, who helped coordinate the workshop, and lastly you people who attended the workshop and participated in the discussions. I noted that roughly 40-50 attended most of the sessions. Thank you, I feel it's been a good experience.

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